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Danny Quentin Johnson
Iowa State University

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JOHNSON, DANNY QUENTIN

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Genetic variability and relationships of physical grain quality traits in BSSS maize

by

Danny Quentin Johnson

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I. INTRODUCTION

Corn production in the U.S. has increased dramatically in the last 45 years and, along with this increase, have been increases in the amount and percentage of the corn that is marketed. Mechanical harvesting and field shelling of high moisture corn have become necessary to handle this quantity of grain. To prevent spoilage of the high moisture corn, high temperature drying has been used. The handling system has had to depend on high speed equipment with large capacity.

The amount and percentage of corn that is physically damaged have increased in recent years because of the present handling methods. Because such physically damaged corn tends to break when it is handled, the cost of this damage is especially great for corn that is marketed. Physically damaged corn is expensive to the farmer-producer, the warehouseman, the consumer, and society. Foreign importers have been particularly aware of quality problems because of the poor condition in which corn reaches them.

Most of the work to improve the quality of corn reaching foreign buyers and the corn to be stored in this country has been in improving the handling processes. Agricultural engineers have put considerable effort into improving the harvest combine, dryers, and loading equipment that is used as corn moves through the market. Although progress has been made in this area, there is still need for considerable improvement in corn quality. Efforts to improve market quality of corn via genotype modification have been minimal because the genetics of physical grain quality traits have not been investigated.

In breeding for superior hybrids, inbred parents are selected to contribute specific characteristics to their hybrid progeny; therefore, the breeder must develop and identify inbred lines that contain desirable attributes. As the theory developed, new testing procedures and selection methods were utilized to increase efficiency. Despite this new technology, the mechanics of the inbreeding process have remained unchanged. Some form of selfing or sibbing must be used to isolate inbred lines with varying degrees of selection during the inbreeding process.

The development and selection of inbred lines is expensive, in terms of time and money. Therefore, desirable inbred lines could be produced more economically if one were able to recognize and eliminate, early in the inbreeding process, those lines that would not be of value for hybrid production. Visual selection will be effective only if plant traits selected for in the inbreds will be expressed in hybrid progenies; therefore, these inbred-hybrid relationships must be understood. In addition, relationships among inbred characters *per se* must also be understood to devise a breeding strategy. A convenient way to study these associations is by the use of correlation analyses.

Correlations between inbred and hybrid traits in corn have been calculated by several investigators. However, few investigators have used unselected material in these studies; consequently, selection may have biased the results of these earlier studies. Selection may have affected the genetic relationships between inbred parents and hybrid progeny. Furthermore, no correlation studies using random genotypes and measuring physical grain quality traits have been reported until this time.

The goal of this research project was to determine the potential for selection of genotypes that are superior for resistance to kernel breakage. Breakage resistance should improve quality for storage, grade, and nutritional value. Specific objectives were:

1) To evaluate corn grain characters in breeding materials that are important in determining market quality of grain;

2) To correlate grain quality characteristics in parent inbred lines with similar characteristics in hybrid progenies;

3) To study the heritability of the important grain quality factors;

4) To develop a rapid technique to enable the breeder to screen selection materials for grain quality; and

5) To develop a quality index that permits quantitative comparison among breeding stocks for grain quality.

II. LITERATURE REVIEW

A. U.S. Grain Standards

An estimate of the quality of corn grain is essential if the grain is to move in the market. Grades function to provide quality specifications for futures contracts, storage contracts, export contracts, and contracts between the country shipper and the processor. Grades also provide a means for reflecting market premiums and discounts that should assure the seller a fair price and should inform the buyer on the condition of the grain being purchased. If a buyer has certain specifications that must be met for the grain to be utilized, the grade of a lot of grain is particularly important.

The need for a grading system in the U.S. was realized as grain production increased, which caused an increase in the amount of marketed corn. Significant differences in quality appeared, thus affecting market values. Market centers developed in the various geographical areas, but each had its own criteria to determine market quality. Quality was based on color, plumpness, and moisture of the corn.

The Chicago Board of Trade was the leader in setting up a grading system for the marketing of grain. Grades were devised for corn in 1857, and inspection fees were 10 cents per car and 25 cents per barge. In 1871, Illinois established an official grain-inspection department under the control of the Railroad and Warehouse Commission. Minnesota followed in 1885 and by 1916 nine states had official standards.

Despite this system, many marketing problems still existed because the grades varied from region to region, state to state, and year to year. There was wide spread public demand for a uniform system. In 1906, the Grain Dealers National Association presented uniform grain grades that were widely accepted, but there was no system to enforce the grades.

Federal grade standards for corn were developed and made effective in July, 1914. The original U.S. standards for corn included the quality factors moisture, damaged corn, cracked corn, and foreign material. There were an additional 11 general rules describing color, condition, and identity of the corn.

Congress passed the United States Grain Standards Act in August, 1916. Under the Act, the corn standards were changed to include: 1) test weight limits of 70.7 and 68.1 kg per hectoliter for grades No. 1 and No. 2, respectively; and 2) the factors cracked corn and foreign material were combined into one factor, BCFM (broken corn and foreign material), and appropriate standards set.

During the period between 1914 and 1934, the Act was amended several times. In 1918, the definition of corn was changed to "shelled corn of the flint or dent varieties." The grade factor "heat damaged and mahogany kernels" was changed to "heat damaged kernels" and the allowable limits were raised in the six grades of corn from 0.0, 0.0, 0.0, 0.5, 1.0, and 3.0 percent to 0.0, 0.1, 0.3, 0.5, 1.0, and 3.0 percent. Minimum test weights per hectoliter of 65.6, 63.0, 60.4, and 56.6 kg were added for grades Nos. 3, 4, 5, and 6, respectively. The terms "commercially objectionable foreign odor" and "heating" were added and the term "firm burned" was dropped from the definition of Sample grade. The terms "immature" and "badly blistered" were dropped from the definition of grade No. 6.

The sieve for determining cracked corn and foreign material was changed from a 5.5 mm (14/64 in.) to a 4.8 mm (12/64 in.)[1] round-hole sieve in 1921.

In 1924, a special grade "Weevily" was created, which was Sample grade that was infested with live weevils or other damaging insects.

The amendment in 1934 caused many changes. The number of numerical grades was reduced from six to five and a special grade for Flint corn was established. Total damage was liberalized from 2, 4, 6, 8, 10, and 15 percent to 3, 5, 7, 10, and 15 percent, and heat damage was liberalized from 0.0, 0.1, 0.3, 0.5, 1.0, and 3.0 percent to 0.1, 0.2, 0.5, 1.0, and 3.0 percent in the five numerical grades. The definition for Sample grade was changed to include the factors "musty" and "sour corn," which were previously included in grade No. 6. Test weights were changed from 70.7, 68.1, 65.6, 63.0, 60.4, and 56.6 to 69.4, 68.1, 65.6, 61.7, and 56.6 kg per hectoliter for the five numerical grades. A limit of foreign grain was established at 10 percent. Moisture limits in grades Nos. 4 and 5 were changed from 19.5 and 21.5 percent to 20.0 and 23.0 percent, respectively. In grade No. 5, the limit for BCFM was changed from 6 percent to 7 percent.

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[1]Hereafter a 12/64-inch round hole sieve will be referred to as a 4.8 mm round hole sieve.

In 1935, the basic method for moisture determination was changed from the Brown-Duvel method to the water-oven method.

The amendment of 1937 added a special grade "Flint and Dent" corn.

The basic method for moisture determination was changed from the water-oven method to the air-oven method in 1959. Test weight allowances were changed from 69.4, 68.1, 65.6, 61.7, and 56.6 kg per hectoliter to 72.0, 69.4, 66.9, 63.0, and 59.1 kg per hectoliter for the five numerical grades.

In 1970, the prefix "U.S." was added to the numerical grade designation. In 1974, "U.S." was changed to "United States Standards." The grade requirements in the official grain standards for corn are presented in Table 1. These requirements are based on three criteria: class, quality, and condition according to the USDA Official Standards of the United States (1978).

The standard classes of corn are yellow, white, and mixed; mixed fails to meet the requirements for the other two classes. The special grades are Flint Corn, Flint and Dent Corn, and Weevily Corn.

The quality criteria generally refer to plumpness, soundness, and cleanliness of the grain. These values are determined by the factors test weight, moisture, damage, and BCFM. Test weight reflects density of the grain and is measured by weighing a specific volume of corn and converting the results to weight per Winchester bushel. Moisture is a measure of storeability. BCFM, which consists of pieces of corn, fines, cob fragments, and other seeds, is an indicator of storeability and handleability. Damaged kernels are defined as kernels that are heat damaged, sprouted, frosted, badly ground damaged, badly weather damaged, moldy, diseased, or otherwise materially damaged.

Condition reflects the state that the grain is in. Heating, odors that are sour or musty and stones, rodent excreta, toxic seeds, or other foreign matter determine condition.

The grain standards should meet several requirements. The standards should be uniform and widely acceptable. The standards should contain the fewest possible factors to identify the quality of the grain and should meet the needs of the trade. Many producers and researchers feel these objectives have not been met and have brought criticism on the U.S. grading standards in the past few years (Bailey, 1968; Grow, 1968; Maywald, 1968; and Uhrig, 1968).

The producer's main complaint is that the market is reluctant to pay premiums, but is willing to assess penalities. This practice encourages the blending of poor quality grain with the higher quality grain, thus resulting in loss of corn that "fits" the described grade. If the money received from dockage at the elevator was paid out as premiums, the producer would be encouraged to produce a higher quality product.

Researchers have pointed out that the grading system has been a reluctant innovator, and technological progress has been extremely slow. There is a need for better-qualified and better-paid sampling personnel. It was also observed that the grading system has failed to recognize the need for better methods of sampling grain. Many of these researchers feel numerical grades are outmoded and counterproductive because they penalize the producer, burden the grain warehouseman, and furnish the user insufficient and often irrelevant information. Maywald (1968) pointed out that much of the domestic corn trade ignore numerical grading and base their contracts on specific factors.

Much of the criticism has been directed toward the quality criteria of the official grain standards: test weight, moisture, damage, and BCFM. Several research workers have pointed out the problems with these quality factors (Bailey, 1968; Bilanski, 1966; Duncan et al., 1972; Hall and Hill, 1974; and Kaminski, 1968).

Hall and Hill (1974) stated that no significant research has been published in the last 100 years to indicate any close relationship between test weight variations of mature corn and its quality for major uses. The authors also suggested that test weight of high moisture corn is strongly influenced by factors that are not related to actual corn quality. Dried corn has a lower coefficient of friction and packs more closely than wet corn, thus the difference in test weight between wet corn and dry corn is caused mainly by the coefficient of friction. This relationship has nothing to do with grain quality. If test weight is to be used as a measure of quality, it must be taken at a comparable moisture and kernel damage level or adjusted to a common basis. Hill (1975) presented data to show that increase in test weight upon drying depended on the initial moisture, amount of kernel damage, drying temperature, the final moisture, and the variety.

The moisture factor associated with grain quality has also been criticized. In the last 20 years, the technology was developed for field shelling of high moisture corn and subsequent drying to acceptable moisture levels. The moisture levels for grades No. 1 through No. 3 are based on those set in 1916. Very little corn is priced or sold as No. 1, which must contain no more than 14 percent moisture. Nearly all corn that is field shelled is dried to levels below 14 percent for storage. There should be a premium paid for corn at these levels or the standards should be changed to meet the technology.

Mahmoud (1972) pointed out that the present grading system does not account for all types of mechanical damage. BCFM, as referred to in the USDA grade standards, is determined by sieving through a 4.8 mm round hole sieve. Large broken kernels and kernels that have stress-cracked endosperms are not included in this factor. Chowdhury and Buchele (1976a) obtained lots of corn that ranged from 0.1 to 3.8 percent BCFM. The amount of visible damage ranged from 16.4 to 79.4 percent. Kline (1973) obtained several combine samples of No. 2 corn that ranged from 0.8 to 17.2 percent breakage, based on the Stein breakage tester. Thus, numerical grade is not indicative of the mechanical damage in a corn sample. Many producers feel the broken corn and foreign material should be separate classes because much of the broken corn is usable and the producers should not be penalized for it.

Shellenberger (1975) discussed new technology that may improve the grain grading system. He suggested that research is on the verge of developing devices for measuring rapidly and accurately moisture, fat, protein, amino acids, and vitamin levels. Research is in progress that should lead to scientific determination of kernel color and hardness. New sampling methods are being developed. Albert (1975) suggested using a total factor approach in which each factor is divided into possible defect categories of none, minor, major, and severe. A table of allowances for each grade would be established. At present, the lowest factor approach is used in that the factor with the lowest level assigns the grade. Another suggestion has been to develop different grade requirements for corn used in feed manufacturing and for corn used in the milling industry. The grain specifications for the two factions are different. For example, feed manufacturers can accept much more broken corn than corn millers.

Table 1. Grades and grade requirements for corn (USDA, 1978)

Grade	Min. TW kg per hectoliter	Moist %	Maximum limits of		
			Broken corn & F.M. %	Damaged kernels	
				Total %	Heat damaged kernels-%
U.S. No. 1	72.0	14.0	2.0	3.0	0.1
U.S. No. 2	69.4	15.5	3.0	5.0	0.2
U.S. No. 3	66.9	17.5	4.0	7.0	0.5
U.S. No. 4	63.0	20.0	5.0	10.0	1.0
U.S. No. 5	59.1	23.0	7.0	15.0	3.0
U.S. Sample Grade	U.S. sample grade shall be corn which does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; or which contains stones; or which is musty, sour, or heating; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.				

B. Losses Caused by Grain Damage

The amount and percentage of corn that is physically damaged have increased in recent years because of the present handling methods. Because such physically damaged corn tends to break when it is handled, the cost of this damage is especially great for corn that is marketed. The need for better quality corn has been brought into focus recently because of quality problems within the export corn market (Anderson, 1972, 1975). The total domestic market is relatively insensitive to quality differences, while the total export market is relatively sensitive to quality differences. The importance of the export market as an outlet for U.S. corn has grown steadily. In the 1930s, the 1 to 5 percent of the U.S. corn was exported and by the 1960s 13.2 percent was being exported even though the total U.S. corn production was two times as great. The projected figure for 1980 is that 40 percent of the U.S. corn will be exported (USDA, 1980b). The projected 1980 U.S. corn production is 164,094,580 metric tons (USDA, 1980a) valued at approximately $134.03 per metric ton; therefore, the total value of the 40 percent that will be exported is $8,797,400,000. The future outlook is for this figure to increase to an even higher level.

The poor condition of grain that reaches overseas buyers has been the basis for complaint. Hill et al. (1979) reported three case studies in which grain was sampled at a number of points in route to a foreign buyer. The corn lots changed up to four grades before the final destination was reached, even though screenings were removed at several points in route. The major cause of grade changes was increased amounts of BCFM.

It is difficult to place a monetary loss on this situation because the buyer compensates the bid price for the grade that is received versus the grade that is purchased. This is an implicit discount that is often overlooked. Anderson (1975) stated that the estimated minimum cost of physical damage was $1.18 per metric ton for U.S. corn exported to Europe in May, 1970. Also, there is concern that increased competition from better quality corn from other corn exporting countries will displace part of the U.S. corn in the increasingly important export market.

In the period between the 1930s and the 1960s, the amount of marketed corn increased from 22 to 50 percent. The farmer-producer has had to deal with discounts at the elevator if the corn being sold was deficient in some grade factor. In Iowa during 1973 to 1975, 56.9 to 73.8 percent of the corn sold was graded No. 3 or lower (USDA, 1975). The amount varied among years because of the genotype by environment interaction. The 1979 Iowa corn production was 41,295,238 metric tons of which 23,949,205 metric tons were sold (USDA, 1979b). If we use an average figure of 66 percent of the corn being graded No. 3 or lower and if the price differential between No. 2 and No. 3 corn is $1.18 per metric ton, then a very conservative estimate of the cost to the Iowa farmer is $18,671,400 per year. Common discounts are $0.78 per metric ton for each 1 percent moisture above 15.5 percent moisture, $0.06 for each 1 kilogram below 72 kg per hectoliter test weight, $0.39 per metric ton for each 1 percent greater than 5 percent total damage, $0.39 per metric ton for each 1 percent between 3 and 5 percent foreign matter, and $0.78 per metric ton for each 1 percent between 5 and 15 percent foreign matter (Uhrig, 1968). Bailey (1968) estimated that broken kernels cost the farmer up to $1.18 on every metric ton of corn sold. Saul and Steele (1966) demonstrated that damaged corn costs more to dry either on the farm or at the elevator.

The warehouseman must also sustain considerable monetary losses that often are passed along to the farmer-producer. Cleaning costs of poor quality corn average $0.39 per metric ton (Bailey, 1968). Large and costly cleaning systems to remove foreign material must be maintained. Screenings that are removed and sold are valued at $3.90 to $7.80 per metric ton lower than graded corn and the storage space that these screenings take up cost $4.68 to $5.46 per metric ton (Dodds, 1972). Broken kernels and foreign material accumulate within the core of the storage bins, containing up to 35 percent screenings. In this area, there is no circulation of air and any heat from fungal growth can not escape, thus leading to heat-damaged corn.

The buildup of dust caused by mechanically damaged corn increases the danger of dust explosions. Also, in some cases air pollution may become a problem that requires costly cleaning equipment. The dust that is collected and disposed of separately from the corn is costly to handle and has considerably less value than the corn.

Whole damaged kernels are more susceptible to molding than are whole undamaged kernels because of abrasions and ruptures in the pericarp that allow mold entry. Heavily damaged corn will deteriorate two to five times as quickly as hand-shelled corn (USDA, 1968). Fungal growth results in increased amounts of heat, water, and carbon dioxide. Molds preferentially attack the germ causing discoloration, and eventually the whole kernel will turn brown. Commercially objectionable musty odors may then develop. Mold growth causes a dry-weight loss and a feeding-value loss as the germ is depleted. Local concentrations of broken corn impede the flow of air so that mold control by aeration is difficult. Recently, the presence of mycotoxins has been identified in some lots of corn. Aflatoxin produced from fungal growth is carcinogenic and renders corn unfit for animal consumption. Because of the strict regulations regarding carcinogens, small numbers of contaminated kernels could cause the condemnation of sizable amounts of grain.

The dry milling industry is affected by poor quality corn, as reported by Roberts (1972). Heat damage reduces the fermentable carbohydrate content and the efficiency of starch separation. Also, the food industry will reject on aesthetic grounds milled particles that appear burnt. Dry-milled products produced from moldy corn are objectionable to the food and brewing industries. Mycotoxins are found in screenings; thus, they are concentrated in the hominy stream that goes into animal feeds. Mechanical damage lowers the yield of primary products because all broken kernels are removed before milling and are diverted to hominy. The miller loses \$6.63 per metric ton of screenings. Stress-cracked kernels decrease the yield of large premium flaking grits that go into breakfast cereals. Brekke (1966) found that stress-cracked kernels increased the degerminator output, thus the endosperm was not adequately rubbed free of the adhering germ. The oil content of the grits increased and oil yield from the germ decreased.

Freeman (1972) discussed how quality factors affect the value of corn for wet milling. Damaged corn reduces the production of primary products because of poor "millability," low oil recovery, low starch viscosity, and low pigment content of the gluten. Heat-damaged corn contains "case-hardened" protein that is not as readily disrupted by steeping in sulfuric acid solutions. Also, heat-damage can cause a 25-percent decrease in grind capacity, poor dewatering of coarse fiber, decreased starch yield, and increased protein content of the isolated starch. The increased fungal growth on mechanically damaged kernels causes decreased oil yield because of depletion of the germ. Molds are primarily responsible for the production of free fatty acids by enzymatically catalyzed hydrolysis of glycerides, thus additional oil is lost. In addition, an approximately equal quantity of good-quality neutral acid is occluded when the free fatty acids are recovered as a soap emulsion.

Van Wormer (1972) reported on the effect of corn damage on the feed manufacturing industry. Over 90,702,948 metric tons of feed are manufactured per year of which two-thirds are complete feed containing cereal grains and their by-products. Corn grain is the largest single ingredient in feed. Feed accounts for 80 percent of the cost of producing meat, milk, and eggs. If corn is deficient in nutrients because of damage or if corn contains some deleterious substance, feed performance suffers. In addition to aflatoxins produced from increased fungal growth, other toxins include ochratoxins, zearalimone, rubitoxin, patulin, and sterigmatocystin, which are all deleterious substances. Some feed manufacturers object to heat-damaged and stress-cracked corn because of palatability problems and increased shattering during grinding. Therefore, poor quality corn is costly for the feed producer and the feed user.

The quality of corn has been shown to affect many facets of industry and society. The problem of poor quality corn exists, and there is economic justification to apply efforts to improve the situation. There is an opportunity to improve the condition of marketed corn from when the crop is in the field until its final use and any point in between.

C. Methods of Evaluating Resistance to Physical Damage

Researchers have developed alternatives to the Official Grain Standards of the United States to evaluate damage levels in corn grain. The grain standards are not sensitive enough for critical comparisons of machinery or genotypes.

1. Visual inspection

Visual inspection is a common method of quantifying mechanical damage of seed for research purposes. Saul and Steele (1966) and Steele (1967) defined mechanical or physical damage as the percentage of total weight consisting of fines, chipped kernels, and kernels with hairline cracks on the seed coat. This technique has been used by other researchers (Agness, 1968; Chowdhury and Kline, 1976, 1978; Cooper, 1968; and Hall, 1968, 1972, and 1974). The main advantage of this system has is that each damaged kernel is examined and separated from the mass of the sample. The main disadvantage is that the method is very time-consuming and human fatigue and subjective judgment can be major factors in the results obtained.

Schmidt et al. (1968) studied the precision of visually estimating mechanical damage in corn. The sources of variation that were investigated included sample size, sampling variation, readers, and random error. The major source of variation was among readers, particularly in the amount of minute damage that was detected. The difference between duplicate readings by the same person was significant in most cases.

Modifications of the technique have been developed to overcome some of the difficulties with the method. Fast Green FCF dye treatment of seeds has been used to make visual inspection easier and faster. Koehler (1957) used this technique for determining pericarp damage in seed corn. Ayers et al. (1972), Chowdhury and Buchele (1978), Fox (1969), Jennings (1974), Keller et al. (1972), Kline (1973), and Waelti (1968) have used this technique successfully. The dye specifically adheres to the exposed starch when the pericarp is ruptured. Schmidt et al. (1968) ran the same precision experiment with Fast Green FCF dyed samples. The dye treatment permitted more damage to be detected, but the precision was not improved.

Researchers have attempted to develop techniques to divide total visible damage into severity classes because mechanical damage occurs on a continuous scale from nicks on the pericarp to complete breakage. Brass and Marley (1973), Chowdhury and Buchele (1975, 1978), and Paulsen and Nave (1978) sorted kernels into various classes of damage ranging from severe damage to sound kernels. Chowdhury and Kline (1978) and Thompson and Foster (1963) divided the severity of stress cracks into classes ranging from sound kernels to multiple cracks in the endosperm. This qualitative approach has provided a better means of describing damage caused by various shelling, drying, and handling procedures. There are still the difficulties of human fatigue, judgement, and the time-consuming nature of the method.

2. Germination and seedling growth tests

The standard germination test has been widely used as an indicator of seed quality in the seed industry. Normally, seed is placed in a dark germination chamber at 25 C for 7 days. Physical damage is only one of the many factors that affects germination. Disease and insect damage can reduce germination and, if the germ is not damaged, partial kernels will germinate. Bakker-Arkema et al. (1972) and Brown et al. (1979) used the standard germination test as a measure of internal damage. Chowdhury and Buchele (1976a) found that the average germination decreased as severity of damage increased. Gomez and Andrews (1971) reported that the standard germination test did not effectively measure the initial quality level of seed corn. Kaminski (1968) stated that the test was an overestimation of seed quality because ideal conditions were provided.

Cold germination tests have also been used by the seed industry to determine seed quality and seedling vigor. For this test, seed is placed in sand for 7 days at 10 C and then transferred to a germination chamber at 25 C for 7 days. Koehler (1957) used the cold test to evaluate how mechanical injury was affected by moisture content of seed corn. Chowdhury and Kline (1976) studied the effect of compression loading on different kernel orientations using this technique. Kaminski (1968) stated that the cold germination test is more meaningful than the standard test because the results were more applicable to field conditions. Gomez and Andrews (1971) found the cold test to be more indicative of the actual mechanical injury when compared with the standard test.

The acid germination test has been promoted by the National Institute of Agricultural Engineering, Silsoe, England. The seed is soaked in a 50 percent (v/v) sulphuric acid solution for 3 hours at 20-21 C. The seed is then washed in running water and treated in a 2-percent calcium carbonate suspension for 15 minutes before being placed in a germination chamber. The acid penetrates any cracks in the pericarp and destroys the embryo, thus mechanically damaged seed will not germinate. Caldwell and Hampson (1958) acid-treated corn seed, but had trouble with mold development. Kaminski (1968) found that this test was very sensitive, but the results were difficult to relate to field conditions.

Seedling growth rate (SGR) tests have been used to evaluate seed quality. For this test, seeds are placed in a dark germination chamber at 25 C for 7 days. The seedlings are then dried at 80 C for 24 hours and weighed. The dry weight of the normal seedlings is divided by the number of seedlings to obtain a SGR of mg/seedling (Burris et al., 1969). Koehler (1957) correlated vigor tests to various types of pericarp damage. Chowdhury and Kline (1976) used this method to evaluate internal damage from compression loading.

3. Numerical damage index

Chowdhury and Buchele (1976a) developed a numerical damage index for qualitative as well as quantitative evaluation of grain damage. Corn was visually divided into five levels of severity as follows:

d_1 = Broken kernels and fines that passed through a 4.8 mm round-hole sieve.

d_2 = Severe damage--broken, chipped and crushed kernels (more than 1/3 of the whole kernel missing).

d_3 = Major damage--open cracks, chipped and severe pericarp damage.

d_4 = Minor damage--hairline cracks and spots of pericarp missing.

d_5 = Sound kernels.

D_1 to D_5 are biological weights based on germination percentage. The equation they developed was:

$$\text{Damage Index, D.I.} = \frac{D_1d_1 + D_2d_2 + D_3d_3 + D_4d_4 + D_5d_5}{10}$$

Jennings (1974) developed a quality index to rank hybrid varieties of corn. The index was determined using the following formula:

$$QI = \frac{150-100\ (a\cdot\%\ F.M) + \%\ P.D. + (b.\%B)}{D.T.W.}$$

where: QI = quality index; a = constant (determined by dividing the average percent physical damage by percent foreign matter); percent F.M. = percent foreign material; percent P.D. = percent physical damage; b = constant (determined by dividing the average percent physical damage by percent breakage); percent B = percent breakage; D.T.W. = dry test weight.

4. Topographical tetrazolium test

The topographical tetrazolium test was developed for determining the germinating capacity of seeds. A kernel is split longitudinally and the embryo is stained with a 1-percent aqueous solution of 2,3,5-triphenyl tetrazolium chloride. The tetrazolium reacts with an enzyme, supposedly present only in live embryos, causing a red coloration of the embryo. Chowdhury and Buchele (1975) and Chowdhury and Kline (1976) used this technique to evaluate internal damage caused by the rubber roller sheller and compression loading, respectively. Kaminski (1968) reported that the method has been shown to be unreliable by some researchers.

5. Carbon dioxide production method

Steele (1967) studied the effect of mechanical damage on grain respiration. The method was developed on the premise that grain deterioration is related to respiration of the grain itself and of accompanying microörganisms. Also, damaged embryos will respire more CO_2 than undamaged embryos. The tests were based on the following respiration equation for a typical carbohydrate:

$$C_6H_{12} + 6O_2 \rightarrow 6CO_2 + 6H_2O + 673 \text{ Cal.}$$

Under controlled conditions for temperature, aeration, and moisture, the respiratory processes of mold growth and the grain itself were found to be similar. Furthermore, the relationship between loss in dry matter and corn quality was a function of kernel damage, temperature, and moisture content. Saul and Steele (1966) and Steele et al. (1969) found the test to be relatively consistent, but the procedure requires considerable time and specialized equipment.

6. Turbidity analysis

Agness (1968) reported on a bulk test to measure mechanical damage in a sample. The procedure was based on the assumption that rupturing the pericarp will allow liquids to be absorbed more quickly and allow certain substances to be more readily extracted when kernels are soaked in water. Spectrophotometer analysis of the water extract from damaged samples showed more turbidity. However, it was difficult to differentiate levels of damage because the magnitude of differences between readings was usually less than the standard error.

7. Dustiness determination

Martin and Lai (1978) reported on a method to measure dust levels in corn samples. The residual dust was removed by isopropyl alcohol, filtered, dried, and weighed. The correlation coefficient between corn fines, as determined by a 4.8 mm round hole sieve, and residual dustiness was $r = .65$. However, the data showed the amount of broken kernels in a sample was not always related to dustiness.

8. Candling method

Thompson and Foster (1963) used a 150-watt incandescent light source enclosed in a box opening through a small rectangular hole as a candling method for determining stress cracks in individual corn kernels. By positioning kernels over the hole and holding the germinal side toward the light source, cracks were easily detected and classified according to the pattern of cracking. They reported that stress cracks in corn induced during drying and external loading of kernels accounted for increased breakage in subsequent handling. Other researchers who have used this technique to evaluate stress cracking include Brekke (1968), Chowdhury and Kline (1978), Hamilton et al. (1972), Ross and White (1971), Thompson et al. (1969), and White and Ross (1970). This procedure is reliable, but very time-consuming and fatiguing.

9. Photoelectric system

Christenbury and Buchele (1977) developed a photoelectric system for measuring mechanical damage of corn. Mechanically damaged corn kernels were treated with a fluorescent dye (8-anilino-1-nophtholene sulforic acid) that reacts selectively with protein in the endosperm. The sample was ground in a Wiley mill to produce a sample of uniform particulate size to be radiated with ultraviolet light. The resulting fluorescence was recorded with a photodetector. Samples of known percentage damage were tested and the fluorescence increased linearly with increased percentage damage. A linear equation was derived to predict percentage damage with fluorescence level, and the coefficient of determination was $R^2 = .97$.

10. Colorimetric determination

Chowdhury and Buchele (1976b) developed a colorimetric technique to measure both quantitative and qualitative mechanical damage of corn kernels. The test consisted of soaking a sample of corn in 0.1 percent (w/w) Fast Green FCF dye for 10 minutes, rinsing in water for 30 seconds, extracting the dye in 0.01 N NaOH for 1 hour, stirring the sample for 1 the pattern of cracking. They reported that stress cracks in corn induced during drying and external loading of kernels accounted for increased breakage in subsequent handling. Other researchers who have used this technique to evaluate stress cracking include Brekke (1968), Chowdhury and Kline (1978), Hamilton et al. (1972), Ross and White (1971), Thompson et al. (1969), and White and Ross (1970). This procedure is reliable, but very time-consuming and fatiguing.

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The system was developed on the assumption that the damage level is directly proportional to the total exposed endosperm area of the kernels in a corn sample. Furthermore, if the dye used in the system follows the Lambert-Beer Law, then the amount of dye taken up by a sample can be measured by a spectrophotometer. The dye adheres only to exposed endosperm and the kernel tip.

Samples of known damage area were tested to determine the relationship between absorbency and damage area. A positive linear response was observed. Chowdhury (1978) further refined this technique. Al-Jalil et al. (1980) used this procedure to compare mechanical damage caused by the conventional combine cylinder and an inclined rubber roller sheller.

11. Miscellaneous testers

Several devices have been developed to simulate or accentuate damage caused by the normal grain handling procedure. After treatment with one of these devices the sample is often evaluated using one of the methods for evaluation that have been discussed previously.

The Stein CK-2 breakage tester was designed to measure breakage susceptibility of a grain sample. This test subjects a 100 g corn sample to impact by rotating impeller (1750 RPM) blades in a small container for 2 minutes and then the amount of fine material that passes through a 4.8 mm round-hole sieve is measured (McGinty, 1970). The percentage breakage is reported as the weight of the fine material produced divided by the total weight of the sample. The test measures "breakage tendency" because actual breakage depends both on the physical condition of the grain at the time it is handled and on the actual conditions of the handling system. Miller et al. (1979a) described modifications to standardize this procedure. Results of this test vary with moisture content, variety, and temperature.

McGinty (1970) and McGinty and Kline (1972) compared the Model CK2 Stein breakage tester to the Model No. 2 Cargill grain breakage tester. The Stein tester was found to be superior because the wearing parts could easily be replaced, the design could be standardized, and manufacturing tolerances could be reduced with proper tooling. Both McGinty (1970) and Miller et al. (1979a) found the results with the Stein tester to be repeatable. Stephens and Foster (1976) correlated results obtained with a Stein breakage tester to breakage resulting from normal handling operations and found the device showed relative breakage susceptibility of different lots of corn. Standardization of the testing procedure would be required to predict actual amounts of breakage. Miller et al. (1979a) found a very high correlation ($r = .98$) between the results obtained with the Stein breakage tester and the results from an accelerator that simulated corn falling 30.5 m. The authors stated that the Stein breakage tester could be used to screen for fragile genetic material.

Many other researchers have used this procedure to evaluate mechanical damage to corn (Agness, 1968; Al-Jalil et al., 1980; Cloninger et al., 1975; Duncan et al., 1972; Gustafson et al., 1978; Gustafson and Morey, 1979; Gygax et al., 1974; Jennings, 1974; Kline, 1973; Paulsen and Nave, 1978; and Thompson and Foster, 1963). The major complaints with this test are that results are very sensitive to the moisture content of the grain and the test is unable to pick out very small differences.

Compression loading has been used by Chowdhury and Kline (1976, 1978) to evaluate the effect of moisture and kernel orientation on corn kernel damage caused from impact. A simple Rinck-McIlwaine value spring tester was used to load individual corn kernels. Loesch et al. (1977) used a L.E.E.-Kramer shear press that measured the pressure required to crush a sample to evaluate modified opaque-2 corn lines for kernel hardness. It was concluded that the shear press was effective and would be especially useful for S_2 recurrent selection for increased kernel hardness.

Several miscellaneous damage testing devices have been developed to meet the needs for specific research activities. Bilanski (1966), Srivastava et al. (1976), and Zoerb and Hall (1960) developed pendulum devices to apply low velocity impact to determine the forces required to cause corn kernel failure. Bilanski (1966) developed a high velocity impactor that consisted of a rotating paddle run by an electric motor. Keller et al. (1972) measured damage to corn kernels caused by impact provided by a pneumatic gun. Sharda and Herum (1977) used a centrifugal impeller to toss corn kernels randomly against a steel surface and reported that the device exhibited greater sensitivity to damage susceptibility than did the Stein breakage tester. Miller et al. (1979b) built a grain accelerator that impacted corn against corn at velocities above and below that of corn falling 30.5 m. Hamdy et al. (1977) and Jindal et al. (1979) used a small hammer mill to evaluate breakage characteristics of corn. A variable, specific breakage rate obtained was based on the distribution of the size of particles. The technique was insensitive to sample size.

D. Factors Influencing Kernel Damage

The factors influencing mechanical damage may be divided into two major groups: machine parameters and plant parameters. The machine parameters include all characteristics of the machinery that is used in the handling process. The plant parameters include morphological, physical, and biological characteristics of the cob, kernel, and the genotype in general.

1. Machine parameters

The harvest combine is the first point of mechanical damage in the handling process. In recent years, mechanical damage caused by field shelling has become more of a problem. In 1978, approximately 84 percent of the corn was harvested in the shelled form in Iowa (USDA, 1979a). Several researchers have studied the effect of various machine characteristics on grain damage during the threshing process.

Ayres et al. (1972) conducted a combine survey in nine counties in Iowa, and the mean total damage for 80 combines that were sampled was 34.9 percent. Roberts (1972) reported that, on the average, 25.8 percent of combine-shelled kernels (before artificial drying) had stress cracks. In an extensive combine sampling study conducted for 3 years in Iowa, Kline (1973) found the average visible damage was 5.5 percent and the hidden damage was 40.5 percent. The allowable limit for BCFM for No. 2 grade corn is 3 percent, but in no instance was the official grade determined by the factor BCFM.

Cylinder speed has been shown to be an important variable in determining mechanical damage. Research by Barkstrom (1955), Hall (1968), Morrison (1955), and Pickard (1955) showed that high cylinder speed was the chief factor causing mechanical damage in corn. Arnold (1964) investigated the effect of cylinder speed and diameter, rasp-bar spacing, concave clearance, feed rate, and direction of feed on threshing efficiency and mechanical damage. It was concluded that to reduce damage, lower cylinder speeds must be used, but this would sacrifice threshing efficiency. Chowdhury and Buchele (1978) reported that as cylinder RPM's increased pericarp damage decreased and severe damage increased. Total damage was 26 percent at 450 RPM and 42 percent at 650 RPM. In the past, varying the cylinder-concave clearance has had little effect on reducing mechanical damage.

Chowdhury and Buchele (1978) studied the nature of corn kernel damage inflicted in the shelling crescent of grain combines. It was concluded that about 50 percent of the mechanically damaged corn consisted of fines, severe damage, and crown damage which can be classified as on-the-cob damage. The remaining damage consisted of embryo and pericarp damage or off-the-cob damage. The off-the-cob damage could readily be reduced by redesigning the shelling mechanism so that shelled kernels can immediately leave the shelling crescent.

Researchers have attempted to decrease mechanical damage by modifying the conventional combine cylinder. Hopkins and Pickard (1953) reported corn kernel damage increased considerably when the number of cylinder bars was increased from six to 12. Using high speed photography, it was found that the first blow of the cylinder bar shelled most of the kernels and subsequent blows only contributed to mechanical damage. Cooper (1968) investigated a number of modifications in cylinder bar types. Rubber cylinder bars and fillers reduced total damage very little, from 7 percent in the conventional combine to 6 percent. Increasing header height had a major reducing effect because the bars had a more nearly tangential approach and the initial collision with the cylinder was less abrupt.

Several nonconventional corn shelling machines have been developed in an attempt to decrease shelling injury. Agricultural engineers in Iowa developed a shelling device that consisted of two endless rubber belts rotating in opposite directions at different speeds (USDA, 1967). The kernels were shelled off the ear with an intense squeezing action. Floating springs automatically adjusted the belts to the ear diameter. Corn at 15 percent moisture was shelled with no apparent damage to the kernels. Fox (1969) used the principle of rolling and squeezing to design a rubber roller sheller. Two rollers rotated in the same direction, but at different speeds. Kernel damage ranged from 6 to 9 percent while the range of damage from a combine cylinder was 15 to 22 percent. Brass and Marley (1973) reported on a sheller that consisted of a smooth tread pneumatic roller in combination with a concave and a second pneumatic orientation roller. Shelling was induced by a combination of rolling motion and cyclic compressive loading imparted to the rows of kernels as the ear passed over the concave bars. Kernel damage was 18 percent for this device and 33 percent for the combine cylinder. Rubbercovered concave bars increased damage of high-moisture corn and decreased damage of low-moisture corn. Al-Jalil et al. (1980) tested an inclined roller sheller consisting of three rollers operating at different speeds in the same sense. This mechanism produced significantly less kernel damage when compared to the conventional combine cylinder. Although the newer experimental machines have succeeded in reducing the level of kernel damage, they have lacked other functional requirements such as high shelling efficiency, high capacity, and durability.

The axil-flow rotary combine has recently been developed and the manufacturers have claimed the new machines produce less mechanical injury to grain. In the conventional combine, crop material is presented tangentially to the threshing mechanism. The ear receives one large impact and several smaller impacts. In the axil-flow combine, the crop material is presented axially and the ear receives several small impacts. Centrifugal force provided by the rotor(s) aids in threshing and separation, thus avoiding the need for hard rubbing action between rotor rasps and the concaves. Because the ear is subjected to multiple passes, concave settings need not be as close and mechanical damage is reduced. Also, there is less damage because the grain takes just 3 seconds to clear the rotor(s), which is less than the 9 seconds required to clear the shelling mechanism in the conventional combine (Quick, 1977).

Murray et al. (1977) reported that the single rotor axil-flow combine produced two-thirds as much crackage in corn as the conventional combine. SaijPaul et al. (1977) compared the performance on soybeans of the twin rotor, axial-flow combine with a conventional combine. The authors concluded that the axial-flow combine produced better quality seed with reduced grain loss at the combine rear, less foreign material, and with better mechanical strength. Samples taken by Hamdy et al. (1977) from grain tanks of axial-flow and conventional combines were found not to be significantly different for specific breakage rate. Paulsen and Nave (1978) compared corn damage caused by the conventional, single rotor, and twin rotor combine. Tests were conducted over a number of rotor speeds and grain moisture levels. In most combinations of variables there were no significant differences among combines for the amount of fines, total damage, stress cracks, Stein tester breakage, and test weight. Where there was significance, in most cases the single rotor combine produced the better quality corn.

The practice of field shelling high-moisture corn has made high-temperature drying necessary to prevent spoilage. In Iowa in 1978, approximately 74 percent of the corn harvested was dried artificially (USDA, 1979a).

Two types of damage are attributed to artificial drying, overheating and brittleness. Overheating is characterized by scorching and discoloration and by certain chemical changes in the protein that make starch and gluten separation difficult in wet milling. Brittleness in artificially dried corn is manifested in stress cracks, or checking of the kernels. The corn pericarp is tough and tends to hold the fissured endosperm intact.

Thompson and Foster (1963) showed that shelled corn dried with heated air is two to three times more susceptible to breakage by the Stein breaker than is corn dried with unheated air. As the number of checked kernels in the sample increased, there was a linear increase in breakage. The number of stress cracks in corn increased with increased drying temperature and airflow rate. Most of the stress cracks formed near the end of the drying period while the corn was drying through the moisture range of about 19 to 14 percent.

Ross and White (1971) reported on stress cracking in white corn as affected by drying temperatures, cooling rates, and overdrying. Stress cracking increased as drying air temperatures increased from 54.4 to 104.4 C. Corn dried to final moisture levels of between 10 and 14 percent had between 70 to 90 percent checked kernels. Other researchers have shown that stress cracking and breakage increase with increased drying temperature (Brown et al., 1979; Gustafson et al., 1978; Gustafson and Morey, 1979; Hamilton et al., 1972; Hamdy et al., 1977; Peplinski et al., 1975; and Thompson et al., 1969).

The rate of cooling is an important factor influencing stress crack formation. Rapid cooling that causes rapid contraction of corn kernels leads to stress crack formation. The "Dyeration" process was first presented by Foster (1964). Corn was dried at 93.3 C to 16 to 18 percent and then transferred hot to a cooling bin. The corn was held hot for 6 to 10 hours and then cooled for 10 hours. The corn left the cooling bin at a moisture level between 14 and 15.5 percent. This process reduced the amount of stress cracks and kernel breakage by 50 percent. Thompson et al. (1969) compared the Dyeration process with a counterflow cooler and found more checked kernels and more breakage with the latter. Brown et al. (1979) used three drying methods and evaluated stress crack formation. The low-temperature dyeration, and high-temperature drying caused

2 percent, 20 percent, and 50 percent kernels with stress cracks, respectively. In experiments by Gustafson and Morey (1979), it was concluded that the delayed cooling process increased test weight and decreased breakage, based on the Stein breakage tester.

Researchers have compared types of driers and their effect on corn quality. Bakker-Arkema et al. (1972) tested three types of continuous flow dryers: the concurrent flow, the counterflow, and the crossflow. The concurrent flow caused less breakage than the other types of driers, based on the Stein breakage tester. The peak temperature of the grain in part of the crossflow and all of the counterflow was greater than the peak temperature in the concurrent flow dryer; therefore, the concurrent flow dryer dries corn of higher quality. Gygax et al. (1974) concluded that the concurrent flow dryer produced less stress cracks and breakage with the Stein tester than did the crossflow dryer.

As grain moves through the market, corn kernels are subjected to more mechanical damage each time the grain is handled. The handling system has had to depend on high speed equipment with large capacity because the corn crop has grown steadily and the export market has grown with the increase in production. Unfortunately, these practices have not been conducive to maintaining high grain quality.

Foster and Holman (1973) conducted an extensive study on grain breakage caused by commercial handling methods. A falling grain stream impacting the bottom of a grain bin caused more breakage than any other handling operation tested. Drop height was the most significant test variable in the free-fall drop test, and at 30.5 m breakage in corn ranged up to 14 percent. In a simulation of filling railroad cars the average breakage was 3.2 percent. Breakage in corn handled with a grain thrower averaged about 1.6 percent. Breakage increased as belt speed increased. Impacting a wood bulkhead caused less damage than did a steel bulkhead. The bucket elevator test caused the least damage. For all tests there was less damage with higher moisture and higher temperature corn. The amount of breakage was cumulative and increased a constant amount each time the same lot of corn was handled. Winter and Foster (1968) found that the order of decreasing damage production was free-fall, the bucket elevator, and the grain thrower. Martin and Stephens (1977) found a cumulative effect each of the 21 times a corn lot was handled.

Breakage in corn conveyed in a pneumatic system ranged from 2 percent at a velocity of 1523.9 m.p.m. to 22 percent at a velocity of 2194.4 m.p.m., as reported by Chung et al. (1973). Keller et al. (1972) accelerated corn in a pneumatic system and directed the corn toward an impact surface. The variables tested included kernel velocity, moisture content, impact surface, angle of impact, and size and shape of kernel. Kernel velocity was the most important variable, although reducing the angle of impact from 90 to 45 reduced damage. A urethane impact surface had one-fifth of the damage as a steel surface.

Sands and Hall (1971) reported on damage to shelled corn during transport in a screw conveyor. They found that when the screw conveyor was operated at full capacity, it caused negligible damage (less than 0.1 percent breakage) to dry, shelled corn. When the conveyor was operated at one-fourth capacity damage increased, but did not exceed 1 percent.

Hall (1974) compared a U-trough conveyor, a screw conveyor, and a perforated tube conveyor. The conclusions were to operate the conveyor at full capacity, and the U-trough produced the least damage. The angle of inclination of the conveyor had little effect on breakage and higher moisture corn was damaged more than lower moisture corn.

Stephens and Foster (1977) investigated the effect of flow retarders in reducing grain damage. They compared a cushion box, a spout retarder, and a "retro-air" retarder. The retarders reduced damage, but by a very small amount. The differences in breakage between heat-dried corn and air-dried corn were greatest; therefore, decreasing stress in the drying process may be a more effective way of decreasing handling damage. Ditzenberger (1972) suggested a number of ways to decrease damage in the handling process. The elevator buckets should start upward movement before meeting incoming grain and the boat pulley should be self-cleaning to prevent grain crushing. The elevator discharge should be of proper design to prevent downlegging and re-elevating the grain. Velocity is the major culprit; therefore, flow retarders are helpful. Spouts should be free of dents and misalignment. Cushion boxes reduce damage because grain impacts grain instead of steel.

2. Plant parameters

Research investigating plant parameters and their effects on mechanical injury in corn is very limited. Agness (1968) reported that for combine damage variety differences were significant. Loesch et al. (1977) found genotypic differences for crushing strength among opaque-2 corn lines. Brown et al. (1979) found some commercial hybrids to be more susceptible to dryer injury than others. Cob morphology differences were reported by Sehgal and Brown (1965) for corn inbreds and hybrids. These cob morphology characteristics were related to combining quality of the lines.

Cloninger et al. (1975) found significant differences among four commercial hybrids for breakage with the Stein tester, and the variety differences were greater as plant density was increased. Duncan et al. (1972) and Jennings (1974) observed differences among a number of widely grown single-cross hybrids for visible damage, percent foreign matter, test weight, and breakage with the Stein tester. The authors stated that there was evidence that certain inbred parents were associated with poor grain quality in hybrid combination. It was suggested that parental lines may be selected to contribute quality to single crosses.

Waelti and Buchele (1969) showed that kernel damage was positively related to kernel moisture and that the relationship was logarithmic in the moisture range of about 15 to 38 percent. About 65 percent of the variation in sheller damage among varieties was accounted for by differences in moisture content. Other researchers have shown increased sheller damage with increased moisture level (Agness, 1968; Ayres et al., 1972; Burrough and Harbage, 1953; Hall, 1968; Johnson et al., 1963; Jennings, 1974; Kline, 1973; Mahmoud and Kline, 1972; and Thompson and Foster, 1963). One reason given for increased damage was higher kernel detachment force requirements at higher moisture contents. Using a strain gauge force transducer, Hall (1961) studied the forces required to remove corn kernels from the cob and found that the force decreased as moisture decreased.

Initial moisture content prior to drying has been shown to affect dryer damage (Brekke, 1968; Hamilton et al., 1972; Ross and White, 1971; Thompson and Foster, 1963; and White and Ross, 1970). Differences in moisture content among genotypes can be related to differences in relative maturity and physiological maturity.

Sehgal and Brown (1965) studied cob morphology and its relation to combine harvesting. Characteristics such as rachis-pith ratio, degree of development of the interrow tissue, amount of nodal parenchyma and length and thickness of the rachilla were found to be of major importance in determining the combining quality of the ear. Large pithed cobs split more easily than did small pithed cobs. Cobs with poorly developed interrow tissue tended to split more easily, also. Cob splitting is an undesirable feature because the cylinder is unable to remove kernels from the longitudinal segments and this leads to mechanical damage. Waelti (1967) found that mechanical damage to kernels increased as cob size decreased.

Kernel size and shape have been shown to influence mechanical damage resistance in corn. Koehler (1957) reported that the incidence of crown injury increased as kernel size increased, especially in the flats. Most injury in the rounds was in the face of the germs and there was more total damage in the rounds. Jennings (1974) concluded that large kernel genotypes sustain more physical damage to the kernel than do small kernel genotypes. Loesch et al. (1977) found that shearing strength decreased as size increased and the intermediate flats were the strongest size-class.

Kernel structure may play a role in determining mechanical injury resistance. Bennett (1950) conducted a morphological study on hard- and soft-starch types of corn based on crushing strength. The harder types were found to have more horny endosperm and within this horny endosperm the protein matrix was denser, the starch granules smaller, and the cell nuclei larger.

Mahmoud and Kline (1972) studied the effect of pericarp thickness on corn kernel damage. Direct impact was the major source of severe damage and the pericarp thickness had little effect in preventing crushing and breaking of kernels. Pericarp thickness was highly correlated with hidden damage caused by indirect impact. Jennings (1974) concluded that, although there were significant differences among genotypes, there was no conclusive evidence to show that thickness of the pericarp had any effect on the physical quality factors of corn grain.

A kernel damage prediction formula was developed by Waelti (1968) based on a number of plant parameters. The variables detachment force, kernel strength, initial kernel thickness, final kernel thickness after compression, and cob strength were of predictive value. The coefficient of determination for the formula was $R^2 = 57.9$. Also, kernel moisture was determined to be an important covarient.

E. Genetic Variability in BSSS

Iowa Stiff Stalk Synthetic (BSSS) was developed by G. F. Sprague (1946) from the following 16 lines: Ia. L159, Ia. L224, Ia. Os420, Ia. WD456, Ind. 461-3, Ill. 12E, CI617, CI540, Ill.Hy, Oh.3167B, Ind.AH83, Ind.Tr9-1-1-6, F.B1-7-1, A3G-3-1-3, CI187-2, and LE23. The 16 inbred lines were chosen for being strong stalked. BSSS has had an important role in the success of hybrid corn. BSSS can be considered above average as a source population of lines (e.g. B10, B14, B37, and B73) that either are or have been used in hybrids throughout the U.S. Corn Belt. Surveys reported by Sprague (1971) and Zuber (1975) show that lines originating from BSSS have been used extensively in commercial hybrids. The commercial hybrids developed from the lines originating from the BSSS source population represented 40 to 60 percent of the acreage in United States (National Academy of Science, 1972). BSSS is above average for general combining ability, but only average for yield _per se_.

Many quantitative genetic studies of BSSS have been conducted at the Iowa Agriculture Research Station because of the integral part this population has played in the corn breeding effort at the station. Estimates of genetic parameters for various traits in BSSS have been obtained using a number of statistical techniques. Hallauer (1971) used a design II mating scheme (Experiment I)[1] to obtain variance component estimates. Obilana and Hallauer (1974) grew unselected inbred lines developed by selfing (Experiment II)[1] for their estimates. Both design I- and design II-mated progenies (Experiment III)[1] were grown by Silva and Hallauer (1975) to obtain variance component estimates. Bartual and Hallauer (1976) used unselected inbred lines developed by full-sibbing (Experiment IV)[1] for their estimates. These studies have been summarized by Obilana and Hallauer (1977).

[1]Hereafter studies by Hallauer (1971), Obilana and Hallauer (1974), Silva and Hallauer (1975), and Bartual and Hallauer (1976) will be referred to as Experiments I, II, III, and IV, respectively.

The variance component estimates from these studies are very similar in many cases. Yield may be considered a complex trait with many loci involved in the inheritance of the trait. Estimates for σ^2_G for yield were 156 $\pm$ 29.0, 147 $\pm$ 16.0, 166 $\pm$ 23.6, and 283 $\pm$ 29.3 for Experiments I, II, III, and IV, respectively. Plant height is relatively simply inherited and there are probably few loci involved in the inheritance of this trait. Estimates of σ^2_G for plant height were 143 $\pm$ 15.0, 191 $\pm$ 18.0, 141 $\pm$ 9.8, and 191 $\pm$ 18.5 for Experiments I, II, III, and IV, respectively.

Estimates of the genotype-by-environment interaction give an indication of the sensitivity of the trait to the environment and aid in determining the number of environments required in a testing program for evaluating a trait. The variance component for yield for the main effect was two to four times as large as the variance component for the interaction. Estimates of σ^2_{GE} for yield were 83 $\pm$ 22.0, 44 $\pm$ 5.0, 91 $\pm$ 10.5, and 45 $\pm$ 12.6 for Experiments I, II, III, and IV, respectively. The variance component for plant height for the main effect was six to 40 times as large as the variance component for the interaction estimates of σ^2_{GE} for plant height were 22 $\pm$ 4.0, 15 $\pm$ 2.0, 12 $\pm$ 1.3, and 4 $\pm$ 1.6 for Experiments I, II, III, and IV, respectively.

Estimates of additive genetic variance (σ^2_A) and dominance genetic variance (σ^2_D) were obtained in Experiments I and III. The size of the variance components for yield for σ^2_A and σ^2_D were approximately equal. The estimates for σ^2_A and σ^2_D were 156 $\pm$ 29, 174 $\pm$ 37 and 166 $\pm$ 24, 184 $\pm$ 21 for Experiments I and III, respectively.

Heritability estimates for a trait indicate the probability of gain from selection. The progeny mean heritability estimates for yield were 34.9, 80.2, 59.1, and 89.4 percent in Experiments I, II, III, and IV, respectively. For the trait plant height the progeny mean heritability estimates were 76.8, 92.9, 82.9, and 95.4 percent for Experiments I, II, III, and IV, respectively.

Many other traits were evaluated in Experiments I, II, III, and IV including ear height, ear length, ear diameter, kernel depth, cob diameter, kernel-row number, tassel-branch number, leaf angle, days-to-silk, and days-to-shed. The consensus has been that BSSS contains genetic variability for most traits and progress can be made with selection for the trait. Consequently, it probably has extensive genetic variability for traits affecting grain quality.

F. Inbred-Hybrid Correlations

Development and selection of inbred lines to be used in hybrid combination is an expensive operation. Knowledge of the relation between characters of the inbred lines and their hybrid performance may aid in eliminating undesirable lines early in the inbreeding process. A method to study these relationships has been correlation studies.

In the 1920s, there was a growing interest in hybrid corn as a variety type. Producing inbred lines in corn was a fairly simple operation for corn breeders, but the immediate problem was evaluating these numerous lines in hybrid combinations. Therefore, corn breeders became interested in increasing the efficiency of their testing programs by eliminating some of these lines early in the inbreeding process.

Kiesselbach (1922), in a study of the relation between vigor of pure-line parents and productivity of first generation hybrids, noted that there seemed to be some general correlation between productivity of the pure-line parents and that of their hybrid progeny, although with some exceptions. Richey (1924) concluded from his study that the true value of a pure line lies in the productiveness of its crosses rather than its own performance per se. Furthermore, Richey and Mayer (1925) stated that the final selection of lines for use in crosses must be based upon their performance in crosses.

Hayes (1926) computed correlation coefficients among characters as expressed in different generations of selfing. He obtained the greatest correlations for length of ear, size of seed, and also, in some cases for smut infection and percentage of lodging. The correlation for yield among the different selfed generations was positive, in most cases. Strong correlations were found between yield and characters that were associated with vigor.

Nilsson-Leissner (1927) obtained correlation coefficients between several characters of 23 inbred lines and the same characters in their single crosses. The correlation coefficients between the yield of the F_1 cross and the mean yield of the two parental lines were 0.1852 ± 0.0580 in the group of 14 dent inbreds and 0.7434 ± 0.0427 in the group of nine flint inbreds. Positive correlations were obtained in all cases between characters in the selfed lines and the same characters in the F_1 crosses. The multiple correlations between yield, ear length, number of kernel rows, percentage of second ears, and plant height in the parental lines and yield of the F_1 crosses were 0.6687 and 0.8240 in the dent and flint inbreds, respectively. He concluded, however, the only way to identify superior combinations was by actual trial.

In a similar study to that of Nilsson-Leissner (1927), Jorgenson and Brewbaker (1927) obtained correlations between selfed lines from an open-pollinated variety and F_1 crosses among the lines. Yields of the single crosses were correlated with the averages of their respective parental inbred lines for yield, length of ear, diameter of ear, number of kernel rows, and plant height. The correlations were all positive and ranged between 0.48 to 0.78. The multiple correlation between yield in the F_1 and the characters in the inbred lines was 0.6074.

Among the most comprehensive correlation studies, was the one performed by Jenkins (1929). Correlation coefficients were calculated between 19 characters in inbred parent lines and the same characters in the F_1 crosses, and between some characters of the inbred parent lines and the yield of their F_1 crosses. The correlations between the 19 characters in the inbred parent lines and the same characters in their crossbred progenies were all positive. Significant and positive correlations were obtained between plant height, ear length, ear diameter, and yield of the parent inbred lines and yield of their F_1 crosses. Also, Jenkins found an important relation between vigor characters and yield in the parent inbred lines and the average performance for yield and other characters in their F_1 crosses.

Jenkins (1935) presented data supporting the early testing procedure. He evaluated the effect of inbreeding and selection within 28 inbred lines upon the hybrids made after eight generations of selfing. Topcross data indicated that selection should not be based on phenotypic values of inbred lines, but should be based on crossing tests. Jenkins concluded that the potential worth of an inbred line could be determined by early testing of the topcross progeny.

Richey (1945) reanalyzed Jenkins (1935) data and agreed that test-crosses were a good criterion for determining combining ability at any stage of inbreeding. However, testcrosses were not good indicators of actual worth until fixation had occurred and recessives with large effects and low gene frequencies were eliminated by selection.

Singleton and Nelson (1945) concluded that it was not possible to detect combining ability earlier than the third generation of selfing. This conclusion was based on two conditions: 1) lines were still segregating for combining ability and 2) the difficulty of testing crossbred progenies was great enough that further inbreeding and selection was advisable.

Sprague (1946) presented data supporting Jenkins (1935) proposal of early testing. He evaluated 167 S_0 plants from Iowa Stiff Stalk Synthetic in topcrosses with Iowa Hybrid 13. The correlation coefficient between S_0 topcrosses and S_1 topcrosses was 0.85; therefore, lines of above average combining ability could be selected before proceeding with further inbreeding and visual selection.

Genter (1963) concluded that if additive and dominant gene effects were the principal causes of heterosis, progeny performance in early generation inbred lines should evaluate their combining abilities better than should testcrosses. Lonnquist and Lindsey (1964) correlated S_1 line performance and topcross performance made with a related and an unrelated tester. Positive correlations were obtained between mean yield of the S_1 and topcross performance. The unrelated tester gave the highest correlations. A greater range of expression was observed for the S_1 lines; however, a greater genotype-by-environment interaction was noted.

Nanda (1966) further investigated inbred line performance compared to testcross performance. Eight inbred lines were crossed to an open-pollinated variety and two single crosses. Low correlations were found between the testcrosses and the inbred lines for yield and shelling percentage. The correlations for maturity characters, plant and ear height, and ear length were high enough to be of predictive value.

Russell and Machado (1978) correlated inbred traits with testcross yield at a number of plant densities. They concluded that inbred plant traits had little predictive value for testcross yield and plant density had little effect on the relative values of the correlations obtained. They stated that effective visual selection of inbred lines can be done in early generations for those highly heritable traits in the inbred lines that will be expressed in hybrid combinations. Furthermore, visual selection for ear and grain traits should also be possible to increase the probability of selecting lines with above average combining ability.

Correlation studies between plant and ear traits of 160 random S_7 inbred lines and 320 single-cross hybrids developed from Iowa Stiff Stalk Synthetic were conducted by Gama and Hallauer (1977). Correlation coefficients were calculated between inbred lines *per se* with means of hybrids that had one inbred line in common and between the mean of two inbred parents and their hybrid. The simple correlation coefficient was less than 0.16 in all instances for both procedures. Multiple correlations of plant and ear traits of inbred lines with yield of single crosses were only 0.23 and 0.21 for the two procedures, respectively.

Balko and Russell (1980) obtained correlations between 14 traits in 40 random inbreds from Iowa Stiff Stalk Synthetic and 20 single-cross progenies over five levels of N. The N-treatment had no consistent effects on the magnitude of r-values between inbred parent lines and single-cross progeny. The trait-to-trait correlations combined over N-levels ranged from 0.13 to 0.82. Only two significant correlations were obtained between inbred parent traits and single-cross yield. The multiple correlation coefficient (R) between 14 inbred line traits and single-cross yield was highest at 0 kgN/ha ($R = 0.94$).

Russell and Pierre (1980) investigated the relationship between 29 commercial hybrids and their inbred parents for N content in the grain. The simple correlation coefficients between the hybrids and the means of the two inbred parent lines were 0.84 and 0.65 at two locations, respectively.

In many cases, trait-to-trait correlations between inbred parent lines and their crossbred progeny have been large enough to be of predictive value. Generally, correlations between inbred traits and a complex trait, such as yield, in hybrid progeny have been low. Sample size has affected the results in many correlation studies. Actual genetic worth for yield for an inbred line has had to be determined with actual crosses; however, highly heritable traits have been effectively selected for *per se* in the early stages of inbreeding.

III. MATERIALS AND METHODS

A. Plant Materials

The genetic material for this study was derived from Iowa Stiff Stalk Synthetic. This synthetic, BSSS, was developed by Sprague (1946) in the years of 1933 and 1934 using 16 U.S. Corn Belt inbred lines that were selected as being strong stalked. The importance of this synthetic to the hybrid corn industry for inbred line development has been demonstrated by Sprague (1971) and Zuber (1975).

From the BSSS population two groups of genetic materials were investigated: (1) 80 unselected inbred lines *per se* and (2) the same 80 inbred lines in single-cross hybrids. The 80 inbred lines were obtained from an unselected group of 247 S_7 lines developed by single-seed descent (Hallauer and Sears, 1973). Line development was initiated in 1961-62 when 250 random, unselected S_0 plants were self-pollinated. The resultant 250 S_1 lines were planted ear-to-row in a 10-plant plot. In each row three consecutive plants were self-pollinated to minimize natural and artificial selection within each row. The middle ear of the three self-pollinated plants was saved at harvest to propagate the line to the next generation. This procedure was continued to the S_7 generation and only three lines were lost.

The 80 inbred lines are considered as unselected; however, from the original 247 S_7 lines, lines on either end of the distribution for days to anthesis were excluded to avoid large differences for maturity. Also, seed quantity requirements, prohibited the use of low yielding lines.

None of the lines, however, was selected with any prior information regarding physical grain quality traits.

The second group of material consisted of the 80 inbred lines mated pair-wise to form 40 single-cross hybrids. The pedigrees and entry numbers for these two groups of materials are listed in the Appendix in Tables A1 and A2.

B. Field Procedures

The study was conducted during the summers of 1976, 1977, 1978, and 1979 with two locations each year. The Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa was one location for each of the years. In 1976, 1977, and 1979 the I.S.U. Research Farm near Ankeny, Iowa was used as a location. In 1978, the farm at the Federal Atomic Energy Research Plant near Ames, Iowa was used as a location. Fertilizer applications were 90 kg/ha of P_2O_5, 90 kg/ha of K_2O, and 168 kg/ha of actual N. Weeds were controlled by the combination of Lasso, machine cultivation, and hand weeding.

Unfavorable environments and uncontrollable circumstances resulted in the loss of several locations. In 1977, both locations were discarded because of severe drought. Heavy first-brood and second-brood corn borer (*Ostrinia nubilalis*, Hübner) infestations occurred during the 1978 growing season, with effects of the feeding being more severe on the inbred lines than the single crosses. In addition, severe weed infestation combined with the corn borer (*Ostrinia nubilalis*, Hüber) feeding at the Atomic Energy Farm near Ames to limit grain yield to the point that limited data were obtained at that location. The inbred lines at the I.S.U. Research Farm near Ankeny in 1979 were discarded because of limited grain yield due to stress at the time of pollination. Due to uncontrollable circumstances, I was not able to derandomize the inbred test at the Agronomy Research Farm near Ames; therefore, limited analysis of the data was possible.

The inbreds and single crosses were handled as separate experiments in that the two groups were in separate blocks in each replication. This was necessary to avoid plant-to-plant competition between single crosses and inbred lines.

The experimental field design was a randomized complete block with three replications at each location. The experimental unit for the inbred test was a three-row plot hand-planted at 17 hills per row with hills spaced at 25.4 cm and a row width of 76.2 cm. The three-row plot for the single-cross test consisted of 13 hills. All plots were overplanted and thinned at the five-leaf stage to one plant per hill to give plant densities of approximately 56,600 plants per hectare. In the inbred tests, hills in which the seed failed to germinate, or the seedling did not survive, were replanted with an identifiable inbred (B73) to provide the adjacent plants with competition. Prior to harvest, the B73 plants were cut out.

Two out of the three rows in a plot were harvested with a Massey-Ferguson two-row combine (Model 205). Cylinder speed was 432 rpm's with a rear concave clearance of 1.6 cm. Approximately, a 600 g sample of shelled corn was collected from each plot. From the remaining plot-row 10 ears were hand harvested. An exception to this procedure occurred when a custom-built plot harvestor employing the same type of harvester mechanism and cylinder action found in the (Model No. 602) Ford picker-sheller was used to harvest the 1978 Agronomy Research Farm location.

The shelled grain samples and ear samples were dried in a forced air dryer at 60°C until a uniform moisture level was reached. After a period of time in cold storage the moisture level of the shelled corn samples was 10.5 percent. Variations from the average moisture level of 10.5 percent were insignificant.

C. Plant and Grain Measurements

Maturity data and visual ratings on ear samples were taken on 10 competitive plants per plot from the hand-harvested row. When 10 competitive plants were not present in a row, the competitive plants available were measured. All other grain data were obtained from a 600-g combined sample taken per plot from the remaining two rows. The following measurements were made for each experiment unless otherwise noted.

1. Date of anthesis

Days to anthesis (DATE) was recorded as the number of days from July 1 to the date when 50 percent of the plants in a plot were showing visible anthers. This trait was recorded only at the Agronomy Research Farm location and only in 1978 and 1979.

2. Harvest moisture

Harvest moisture (MOIST) was determined on a wet weight basis using the following formula:

$$\text{moisture \%} = \left(\frac{\text{wet weight - dry weight}}{\text{wet weight}}\right) 100.$$

where: wet weight = 600 g or weight of undried shelled grain sample,

dry weight = weight of dried shelled grain sample.

3. Visual rating

Visual ratings (RATE) were taken on the 10 dried ear samples per plot. The rating was based on endosperm type with a 1 to 5 scale being used for all tests in 1976 and a 1 to 3 scale being used for the single crosses in 1978 and 1979. The rating classes for the inbred tests may be described as follows:

1 = complete flint, essentially no denting;

2 = shallow dent, some kernels not dented;

3 = all kernels dented, essentially no shrivelling of the crown;

4 = full dent, moderate crown shrivelling of all kernels;

5 = full dent, extreme crown shrivelling.

The 1, 2, and 3 scale used for the single crosses was essentially the ratings 2, 3, and 4 of the 1 to 5 scale. Examples of the rating classes are shown in Figures 1 and 2.

4. Breakage test

The moisture content of the grain samples for the breakage tests (BREAK) was approximately 10.5 percent in 1976. In 1978, enclosed humidified chambers were used to temper the grain to about 12.5 percent moisture. In 1979, the moisture variation among samples after tempering was unacceptable; therefore, breakage data were taken on samples with 10.5

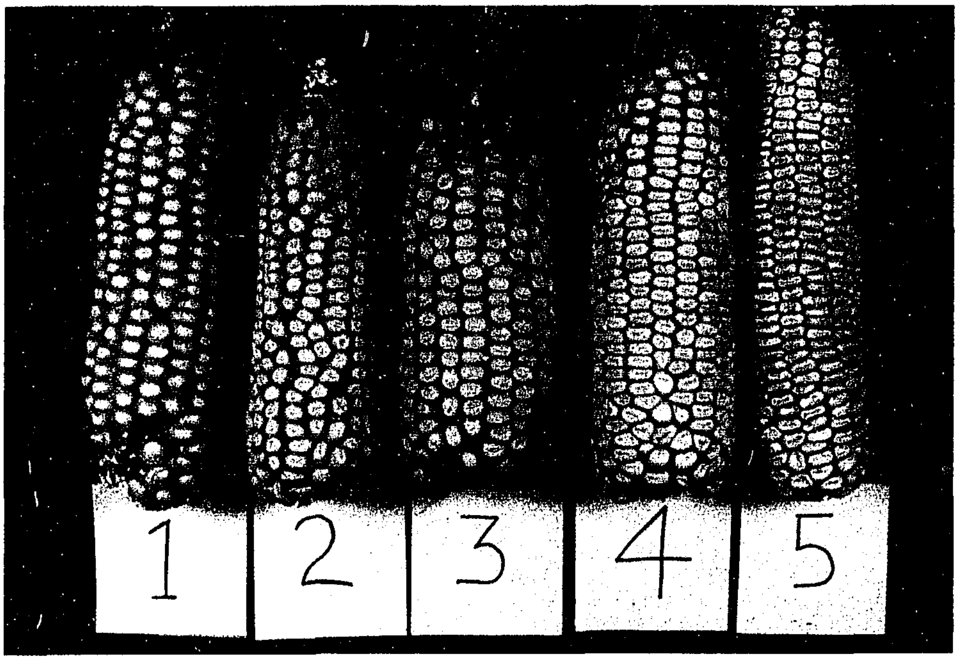

Figure 1. Examples of ear rating class used for visual rating of endosperm type for inbred entries

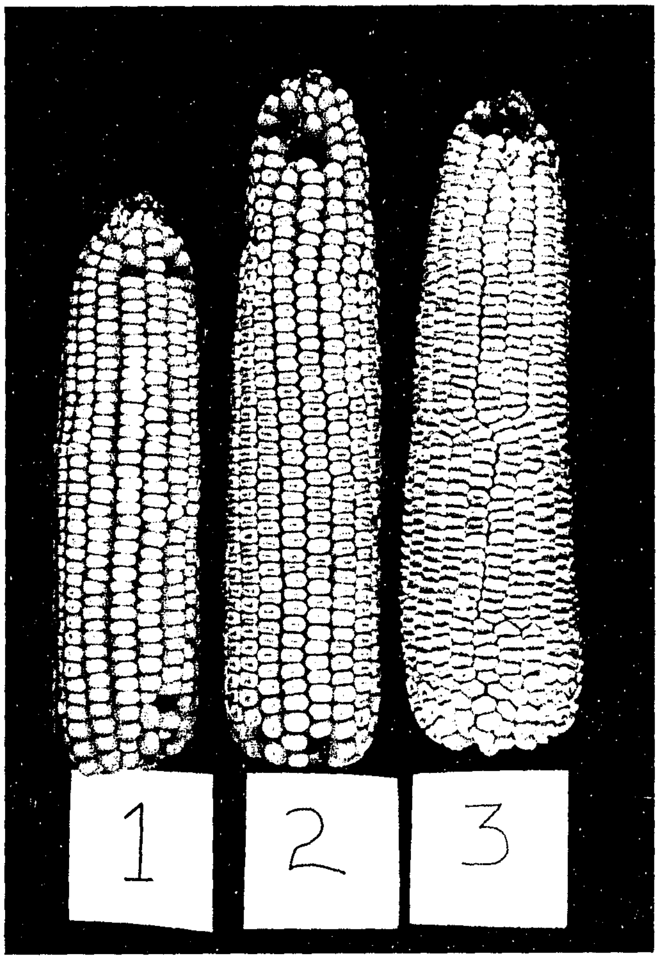

Figure 2. Examples of each rating class used for visual rating of endosperm type for hybrid entries

percent moisture.

In 1976 and 1979, samples were screened with a 4.8 mm round-hole sieve before a 100 g sample to be tested was weighed; thus, the samples contained some large broken kernels. To avoid a confounding with corn borer (Ostrinia nubilalis, Hübner) damage, the 1978 100 g samples were hand picked to include only whole kernels.

The breakage tests were conducted with a Stein CK-2 breakage tester. The Stein tester consisted of an enclosed metal container equipped with an impeller that has blades set at a 45° angle and operated at 1750 rpm's. The time of operation was 2 minutes for 1976 and 4 minutes for 1978 and 1979. The sample was then passed over a 4.8 mm round-hole sieve and fine material and cracked kernels passing through the sieve were weighed to calculate the percentage breakage.

5. 300-Kernel weight[1]

300-Kernel weight (WT) was determined as the weight, to the nearest 0.1 g, of a machine-counted, 300-kernel sample.

6. 300-Kernel volume[1]

300-Kernel volume (VOL) was determined as the volume of water displaced, to the nearest 1 ml, of a machine-counted, 300-kernel sample.

7. Specific gravity[1]

Specific gravity (DEN) was calculated from the following formula:

$$\text{Specific Gravity g/ml} = \frac{\text{weight of 300 kernels}}{\text{volume of 300 kernels}} .$$

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[1]This trait was not measured for the inbreds at the Atomic Energy Farm in 1978 because of a lack of seed.

8. Colorimetric test[1]

The amount of Fast Green FCF dye (GRN) taken up by a 100 g corn sample was measured using a modified procedure of the one developed by Chowdhury and Buchele (1976b). A 100 g sample of shelled corn was immersed for 30 seconds in a 100 ml 0.01 percent (w/w) Fast Green FCF dye solution. The sample was then drained and the excess dye was rinsed off with running tap water for 30 seconds. The adhering dye was then extracted by placing the sample in 250 ml of a 0.05 N sodium hydroxide solution. A sample of the extracted dye solution was poured into a test tube and after 24 hours, the absorbancy of a 3 ml sub-sample was read at 610 nm on a Beckman (Model No. 94) spectrophotometer. These data were not taken in 1976.

Summarization of the abbreviations and their descriptions for plant and grain traits is presented in Table 2.

Table 2. Listing of abbreviations used to describe the plant and grain traits for the inbreds and single crosses

Abbreviation[a]	Description
BREAK	Stein breakage test (%)
MOIST	Harvest moisture (%)
RATE	Visual rating (1-5)
WT	300-kernel weight (g)
VOL	300-kernel volume (ml)
DEN	Specific gravity (g/ml)
GRN	Fast Green dye test (absorbance)
DATE	Days to 50 percent pollen shed from July 1

[a]Abbreviations will be used in all subsequent tables and text to describe the plant and grain traits.

D. Statistical Analyses

1. Analysis of variance and covariance

The standard procedure for the randomized complete block design was used to analyze the data taken for the eight plant and grain measurements. The model used for each character at one environment is as follows:

$$Y_{ij} = u + R_i + G_j + \varepsilon_{ij}.$$

where: Y_{ij} = observed value of the ij^{th} plot,

u = experimental mean,

R_i = effect of the i^{th} replication, $i = 1,2,3$,

G_j = effect of the j^{th} genotype; $j = 1,\ldots,80$ (inbreds) and $j = 1,\ldots,40$ (single crosses),

ε_{ij} = deviation of the observed value, Y_{ij} from its expected value, $\hat{Y}_{ij}$.

For the purpose of calculating the expected mean squares, replications and genotypes were assumed to be random. The source of variations, degrees of freedom, and expected mean squares are shown in Table 3. F-tests for the different characters were made according to the expected mean squares.

Data were combined across all environments without partitioning years and locations because the tests were not grown at each location in each year. The model used for these analyses was:

$$Y_{ijk} = u + E_i + R(E)_{ij} + G_k + (GE)_{ik} + \varepsilon_{ijk}.$$

where: Y_{ijk} = observed value of the ijk^{th} plot,

u = experimental mean,

E_i = effect of the i^{th} environment; $i = 1,\ldots,6$,

$R(E)_{ij}$ = effect of the j^{th} replication within the i^{th} environment; $j = 1,2,3$,

G_k = effect of the k^{th} genotype; $k = 1,\ldots,80$ (inbreds) and $k = 1,\ldots,40$ (single crosses),

$(GE)_{ik}$ = interaction effects of the k^{th} genotype with the i^{th} environment,

ε_{ijk} = deviation of the observed value, Y_{ijk} from its expected value, $\hat{Y}_{ijk}$.

For the purpose of calculating the expected mean squares, environments, replications, and genotypes were assumed to be random. The source of variations, degrees of freedom, and expected mean squares are shown in Table 4. F-tests for the different characters and their interactions were made according to the expected mean squares.

The L.S.D. (Steel and Torrie, 1960) was used to compare means at the 0.05 level of significance. L.S.D.'s for mean comparisons were calculated as follows:

$$\text{L.S.D.} = t\left[\frac{2\sigma_e^2}{r}\right]^{\frac{1}{2}} .$$

Where: L.S.D. = least significant difference,

t = Student's t statistic with n-1 degrees of freedom and the 0.05 probability level,

r = number of observations in a mean,

σ^2_e = error mean square (σ^2_e).

Estimates of variance components were obtained from expected mean squares in the combined analysis of variance (Table 4) as follows:

$$\hat{\sigma}^2_e = M_1,$$

$$\hat{\sigma}^2_{GE} = \frac{M_2 - M_1}{r},$$

$$\hat{\sigma}^2_G = \frac{M_3 - M_2}{re} .$$

The variances of the estimates were calculated as outlined by Comstock and Moll (1963). The finite correction factor (Mode and Robinson, 1959) was added to give the following formulae:

$$v(\sigma^2_G) = \frac{1}{(re)^2}\left[\frac{2(M_3)^2}{(g-1)+2} + \frac{2(M_2)^2}{(g-1)(e-1)+2}\right],$$

$$v(\sigma^2_{GE}) = \frac{1}{(r)^2}\left[\frac{2(M_2)^2}{(g-1)(e-1)+2} + \frac{2(M_1)^2}{e(r-1)(g-1)+2}\right] .$$

The combined analysis of variance and covariance performed for all pairs of traits is shown in Table 5. Components of covariance were calculated as follows:

$$\hat{\sigma}_{e_{XY}} = M_{1_X} M_{1_Y},$$

$$\hat{\sigma}_{G_{XY}} = \frac{M_{3_X}M_{3_Y} - M_{2_X}M_{2_Y}}{re} \quad .$$

2. Estimates of heritability

Heritability values on a per-line-mean basis for the inbreds were calculated from the combined analysis of variance by the following formula (Table 4):

$$h^2 = \frac{\hat{\sigma}^2_G/2}{\frac{\hat{\sigma}^2_G}{2} + \frac{\hat{\sigma}^2_{GE}}{2e} + \frac{\hat{\sigma}^2_e}{re}} \quad .$$

where: h^2 = heritability estimate,

$\hat{\sigma}^2_G$ = genotypic variance,

$\hat{\sigma}^2_{GE}$ = genotype x environment interaction variance,

$\hat{\sigma}^2_e$ = error variance,

e = number of environments,

r = number of replications.

The estimates involving $\hat{\sigma}^2_G$ were divided by two because the genetic variation among inbred progeny is equal to two times the additive genetic variance (assuming epistasis is absent) in the original population.

3. Simple and genotypic correlations

Correlations between pairs of traits were performed by various methods as follows: correlations among the inbred traits *per se*, among the hybrids *per se*, and the mean of the traits for the two inbred parents with the traits of their respective single cross. All correlations were calculated on an entry mean basis.

The appropriate simple correlations for inbred and hybrid traits *per se* pooled over environments were derived by the following formula (Table 5):

$$r_{pn_{XY}} = \frac{M_{3_X} M_{3_Y}}{\sqrt{M_{3_X} \cdot M_{3_Y}}} .$$

where: $r_{pn_{XY}}$ = simple correlation coefficient for traits X and Y,

$M_{3_X} M_{3_Y}$ = genotypic mean cross product (covariance) for traits X and Y,

M_{3_X} = genotypic mean square for trait X,

M_{3_Y} = genotypic mean square for trait Y.

Tests of significance were made using the following T-test (Steel and Torrie, 1960):

$$T = \frac{r}{\sqrt{1-r^2/n-2}}$$

where: T = Student's t statistic with n-2 degrees of freedom,

r = simple correlation coefficient,

n = number of paired observations.

Components of variation and covariation (Tables 4 and 5) were used to estimate genotypic ($r_{g_{XY}}$) correlations (Mode and Robinson, 1959). The following formula was used for these calculations:

$$r_{g_{XY}} = \frac{\hat{\sigma}_{G_{XY}}}{\sqrt{\hat{\sigma}^2_{G_X} \cdot \hat{\sigma}^2_{G_Y}}}$$

where: $r_{g_{XY}}$ = genotypic correlation coefficient for traits X and Y,

$\hat{\sigma}_{G_{XY}}$ = genotypic covariance between traits X and Y,

$\hat{\sigma}^2_{G_X}$ = genotypic variance of trait X,

$\hat{\sigma}^2_{G_Y}$ = genotypic variance of trait Y.

The simple correlations between inbred traits and hybrid traits were calculated as follows:

$$r_{XY} = \frac{\Sigma_{xy}}{\sqrt{\Sigma x^2 \Sigma y^2}} \quad .$$

where: r_{XY} = simple correlation coefficient for traits X and Y,

X = (Parent 1 + Parent 2)/2,

Y = Hybrid,

Σxy = corrected sums of cross products for X and Y,

Σx^2 = corrected sums of squares for X,

Σy^2 = corrected sums of squares for Y.

Table 3. Source of variations, degrees of freedom, and expected mean squares for the analysis of variance at one location

Source	df	MS	E(MS)
Replications (R)	r-1	M_3	
Genotypes (G)	g-1	M_2	$\sigma_e^2 + r\sigma_G^2$
Error	(r-1)(g-1)	M_1	σ_e^2
Total	rg-1		

Table 4. Source of variations, degrees of freedom, and expected mean squares for the combined analysis of variance

Source	df	MS	E(MS)
Environments (E)	e-1		
Replications/E	e(r-1)		
Genotypes (G)	g-1	M_3	$\sigma_e^2 + r\sigma_{GE}^2 + re\sigma_G^2$
G x E	(g-1)(e-1)	M_2	$\sigma_e^2 + r\sigma_{GE}^2$
Error	e(r-1)(g-1)	M_1	σ_e^2
Total	erg-1		

Table 5. Analysis of variance, covariance and expectations of mean cross products for a pair of traits (X and Y) over environments

Source	df	Mean squares Trait X	Mean squares Trait Y	Mean cross product	Expected mean cross product
Environments (E)	e-1				
Replications/E	e(r-1)				
Genotypes (G)	g-1	M_{3_X}	M_{3_Y}	$M_{3_X} M_{3_Y}$	$\sigma_{e_{XY}} + r\sigma_{GE_{XY}} + re\sigma_{G_{XY}}$
G x E	(g-1)(e-1)	M_{2_X}	M_{2_Y}	$M_{2_X} M_{2_Y}$	$\sigma_{e_{XY}} + r\sigma_{GE_{XY}}$
Error	e(r-1)(g-1)	M_{1_X}	M_{1_Y}	$M_{1_X} M_{1_Y}$	$\sigma_{e_{XY}}$
Total	erg-1				

Table 6. Listing of abbreviations used to describe the 16 selection indices constructed for the inbred entries

Abbreviation[a]	Description
	Elston's Index
E1	Traits: RATE, BREAK, GRN
E2	Traits: RATE, BREAK
E3	Traits: BREAK, GRN
E4	Traits: RATE, GRN
E5	Traits: BREAK
E6	Traits: RATE
E7	Traits: GRN
	Restricted Index
R1	Traits: MOIST, RATE, BREAK, WT, GRN Restriction: No change in MOIST, WT
R2	Traits: MOIST, RATE, BREAK, WT, GRN Restriction: No change in MOIST, 10% change in WT
	Rank Summation Index
RS1	Traits: RATE, BREAK, GRN
RS2	Traits: RATE, BREAK
RS3	Traits: BREAK, GRN
RS4	Traits: RATE, GRN
RS5	Traits: BREAK
RS6	Traits: RATE
RS7	Traits: GRN

[a]Abbreviations will be used in all subsequent tables to describe the selection indices.

Tests of significance were made using the T-test (Steel and Torrie, 1960):

$$R = \frac{r}{\sqrt{(1-r^2)/n-2}} .$$

where: T = Student's t statistic with n-2 degrees of freedom,

r = simple correlation coefficient,

n = number of paired observations.

4. Selection indices

All inbred lines were ranked lowest to highest based on various selection indices as follows: the rank summation index, the Elston (1963) weight-free index, and the restricted index. Summarization of the abbreviations and their descriptions for the various selection includes are presented in Table 6. All indices were calculated on an entry mean basis pooled over environments.

The rank summation index values (Mulamba and Mock, 1978) were calculated by summing the ranks of the traits as follows:

$$I = \sum_{i=1}^{n} \text{Rank } X_i .$$

where: I = index value,

Rank X_i = rank of the X_i th trait out of n^{th} traits.

The Elston (1963) weight-free index values were calculated as:

$$I = (X_i - \ell_i)(X_{i+1} - \ell_{i+1})\ldots(X_n - \ell_n)$$

where: I = index value,

X_i = observed value of the X_i th trait,

ℓ_i = minimum value of the X_i th trait.

The weights for each restricted index (James, 1968) were calculated. An adaption to James (1968) procedure, explained in detail by St. Martin (1980), was used as follows:

$$b = [I - P^{-1}Q'(QP^{-1}Q')^{-1}Q]P^{-1}Ga.$$

where: b = matrix of weights for the traits,

I = n x n identity matrix,

P = phenotypic variance-covariance matrix,

Q = restriction matrix,

G = genotypic variance-covariance matrix,

a = economic weight index.

Spearman's rank correlations (Steel and Torrie, 1960) were calculated to correlate the rankings based on the different selection indices. The following formula was used:

$$r_s = 1 - \frac{6 \sum_i d_i^2}{(n-1)n(n+1)}$$

where: r_s = Spearman's rank correlation coefficient,

d_i = difference in ranking,

n = number of paired observations.

Tests of significance were made using the following T-test (Steel and Torrie, 1960):

$$T = r_s \sqrt{\frac{n-2}{1-r_s^2}}$$

where: T = Student's t statistic with n-2 degrees of freedom,

r_s = Spearman's rank correlation coefficient,

n = number of paired observations.

Selection differentials for each trait for the various indices were calculated as follows:

S.D. = Population $\bar{X}$ - Selected Population $\bar{X}$.

where: S.D. = selection differential,

Population $\bar{X}$ = mean of entire population,

Selected Population $\bar{X}$ = mean of the top 20% of the population.

IV. RESULTS AND DISCUSSION

A. Analyses

The materials for this study were grown in the crop years of 1976, 1977, 1978, and 1979. The 1976 growing season was dry, but yields were high enough to provide the quantities of corn grain required for the laboratory analyses. In 1977, no materials were harvested because of severe drought that caused poor pollination and seed set. Potential grain yields, especially the inbreds, at both locations in 1978 were reduced because of heavy infestations of first- and second-brood European corn borer (*Ostrinia nubilalis* Hübner). The heaviest infestations were at the Atomic Energy location, and this, coupled with heavy weed growth, reduced the inbred grain yield so that only limited analyses could be performed. The 1979 growing season was generally excellent, but the inbred test at Ankeny had to be discarded because of poor pollination caused by heat stress at the time of anthesis. Because of a derandomization problem with the inbred test at Ames in 1979, plot-mean correlations were the only statistical analyses possible. Adequate grain samples were obtained for the single crosses in every year except 1977.

1. Inbred plant and grain traits

Mean values and ranges of inbreds for the eight plant and grain traits pooled over entries are presented in Table 7. (Mean values for each inbred entry at each environment are presented in Appendix Tables A3 to A9). The mean value for MOIST was high (23.3%) in the 1976 Ankeny environment and low (13.7%) in the 1978 Atomic Energy environment. Ranges

Table 7. Mean values and ranges of eight plant and grain traits pooled over entries for inbred tests

Test		MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/m	GRN[a] Absorbance	DATE Days
1976 Ames	Mean	17.7	2.7	10.8	64.8	53.1	1.22	---	----
	Range	7.7-30.9	1.2-4.8	4.2-40.4	41.0-97.7	32.3-78.0	1.05-1.35	---	----
1976 Ankeny	Mean	23.3	2.8	16.7	74.6	58.5	1.28	---	----
	Range	14.5-33.4	1.7-4.2	6.7-36.1	51.4-106.9	37.0-84.7	1.11-1.40	---	----
1976 Combined	Mean	20.5	2.7	13.8	69.8	55.9	1.25	---	----
	Range	11.3-32.2	1.6-4.9	6.4-37.5	47.1-98.1	34.7-80.3	1.09-1.36	---	----
1978 Ames	Mean	16.7	2.6	5.2	66.3	57.7	1.15	8.8	26.2
	Range	12.5-26.2	1.0-4.7	1.2-17.5	44.0-98.1	36.3-84.0	1.00-1.34	3.9-17.7	18.3-40.0
1978 Atomic Energy	Mean	13.7	2.4	9.8	----	----	----	---	----
	Range	9.8-21.3	1.0-5.0	3.1-23.0	----	----	----	---	----
1978 Combined	Mean	15.2	2.5	7.4	66.3	57.7	1.15	8.8	26.2
	Range	11.1-23.1	1.2-4.8	2.3-19.7	44.0-98.1	36.3-84.0	1.00-1.34	3.9-17.7	18.3-40.0
Combined	Mean	17.9	2.6	10.7	68.7	56.5	1.22	8.8	26.2
	Range	12.5-24.6	1.5-4.9	4.9-27.7	47.4-94.4	38.2-80.7	1.10-1.30	3.9-17.7	18.3-40.0

[a]Values were multiplied by 10^2.

for MOIST were greater for 1976 than 1978. The differences in harvest moisture observed may have been manifested by greater values for BREAK in 1976. Variations in MOIST were caused by differences in drying conditions in the fall and the date of harvest.

The means and ranges of BREAK were greater in 1976 (mean = 13.8%, range = 6.4-37.5%) than in 1978 (mean = 7.4%, range = 2.3-19.7%). The grain was broken at a lower moisture content (10%) in 1976 than in 1978 (12.5%), which was probably the primary cause of these year-to-year differences. Seed size, as measured by the mean of WT, was greater in 1976 (69.8 g) than in 1978 (66.3 g) because of more favorable growing conditions in 1976. Ranges for WT and VOL were similar from year to year. The corn kernels in 1976 were denser (1.25 g/ml), as measured by the mean of DEN, than in 1978 (1.15 g/ml). However, the ranges were greater in 1978. The means and ranges of RATE were relatively unaffected by environment, as might be expected because the scale of measurement was set relative to the environment. The traits, GRN and DATE, were measured in only one environment.

The combined analyses of variance for the inbred tests presented in Table 8 indicate that highly significant differences among genotypes were observed for all traits. (Analyses of variance for each environment are presented in Tables A10 to A15.) Also, highly significant genotype x environment interactions were obtained for all traits except GRN and DATE, which were evaluated in only one environment. Examination of inbred means in Tables A3 to A9 reveal that the significant genotype x environment interactions were probably caused by a change in magnitude rather than a change in rank.

Table 8. Analyses of variance for eight plant and grain traits for 80 inbred entries, data combined over locations and years

Source d.f.	Mean squares							
	MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Environments (E) (3)[c] 2 [d]{1}[e]	3751.40	635.82	5203.40	6585.63	1975.33	9692.18	---	---
Replications/E (8) 6 {2}	21.42	73.50	24.66	122.19	137.06	80.34	15.37	21.55
Genotypes (G) (79) 79 {75}	110.13**	419.88**	184.08**	1145.65**	818.27**	168.92**	26.69**	38.48**
G x E (229) 153 {0}	19.38**	52.85**	26.86*	123.77**	87.26**	47.70**	---	---
Error[f] (616) 466 {150}	6.17	19.52	7.99	28.76	26.43	32.85	3.41	4.30

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]Degrees of freedom for MOIST, RATE, BREAK.

[d]Degrees of freedom for WT, VOL, DEN.

[e]Degrees of freedom for GRN, DATE.

[f]See Table A16 for error degrees of freedom.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

A clearer understanding of the relative importance of the various sources of variation in the inbred tests can be determined by examining the magnitude of variance component estimates from the combined analyses of variance. Genotypic (V_G) and genotype x environment (V_{GE}) variances are presented in Table 9. Estimates for V_G and V_{GE} were significantly different from zero for all traits. The magnitude of V_{GE} compared to V_G is an important consideration when developing a testing program. The relative size of V_{GE} was from 25 percent (VOL) to 58 percent (MOIST) as large as V_G. The magnitude of V_{GE} estimate for BREAK may have been inflated because of differences in the testing procedure from year to year. These estimates for V_G and V_{GE} may be compared with those obtained for BSSS by Obilana and Hallauer (1974). They reported that V_{GE} ranged from 3 percent (ear height) to 95 percent (ear diameter) as large as V_G. Their estimate for grain yield V_{GE} was 30 percent, which is comparable to the grain quality trait V_{GE} estimates in my study.

The heritability estimate for each trait is also shown in Table 9. All heritability estimates were greater than 75 percent, except DEN, which was 39 percent. The low heritability of DEN was caused by the large estimate for error variance (V_e). Obilana and Hallauer (1974) obtained heritability estimates for other traits in BSSS that were of similar magnitude to my estimates. The estimates for GRN and DATE may have been even larger if an estimate of V_{GE} could have been removed from the estimate of V_G.

Table 9. Genotypic (V_G) and genotype x environment (V_{GE}) variances with standard errors, error (V_e) variance and heritability estimates for inbred plant and grain traits, data combined over locations and years

Traits	V_G	V_{GE}	V_e	h^2
MOIST	7.56 ± 1.45	4.40 ± 0.62	6.17	0.78
RATE[a]	3.06 ± 0.55	1.11 ± 0.17	1.95	0.84
BREAK	13.10 ± 2.42	6.29 ± 0.85	7.99	0.82
WT	113.54 ± 20.06	31.67 ± 1.93	28.76	0.87
VOL	81.22 ± 14.33	20.28 ± 3.36	26.43	0.86
DEN[b]	13.69 ± 3.00	4.28 ± 1.88	32.85	0.39
GRN[b]	7.76 ± 1.45	----	3.40	0.77
DATE	11.39 ± 2.07	----	4.30	0.80

[a]Values were multiplied by 10^1.

[b]Values were multiplied by 10^4.

2. Inbred correlation analyses

Simple and genotypic correlation coefficients between pairs of traits for the inbred lines were calculated to determine the important relationships among the eight plant and grain traits. These correlation coefficients calculated for data combined over environments are presented in Table 10. (Correlation coefficients for each environment are presented in Tables A17 to A23.) Generally, the simple correlation coefficient is of slightly lower magnitude than the genotypic correlation coefficient calculated for each pair of traits. Differences between the two estimates would be attributed to genotype x environment and error correlations. Further discussion will be based on simple correlation coefficients.

Significant, positive correlations were obtained for MOIST with BREAK, WT, VOL, GRN, and DATE. As harvest moisture increased, damage susceptibility increased (BREAK and GRN), seed size increased (WT and VOL), and genotypes became later (DATE). There was a significant, positive correlation between RATE and BREAK and a significant, negative correlation between RATE and DEN. The more floury kernel (deeply dented) types tended to break more than the hard kernel (flinty) types and to have a lower specific gravity.

BREAK was positively correlated with WT, VOL, and GRN. The larger kernels tended to be more susceptible to breakage. The magnitude of the correlation with GRN ($r = .22$) was smaller than expected. Evidently, the two variables were not measuring exactly the same damage. GRN quantified combine damage, while BREAK measured combine damage plus simulated additional handling damage. Also, GRN measured the surface area

Table 10. Correlation coefficients between eight plant and grain traits for 80 inbred entries, data combined over locations and years (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.01	0.33**	0.51**	0.48**	0.06	0.34**	0.33**
RATE	-0.01		0.35**	0.08	0.18	-0.55**	0.04	-0.12
BREAK	0.34	0.41		0.47**	0.57**	-0.52**	0.22*	0.09
WT	0.64	0.09	0.55		0.98**	-0.04	0.07	-0.01
VOL	0.61	0.20	0.66	0.98		-0.24*	0.13	0.01
DEN	0.03	-0.59	-0.61	-0.06	-0.25		-0.24*	-0.13
GRN	0.38	0.06	0.20	0.06	0.15	-0.39		0.28*
DATE	0.39	-0.17	0.10	-0.01	0.02	-0.23	0.27	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

of exposed endosperm caused by chipping or cracking of the pericarp, which is not necessarily related to the total surface area of a kernel. A significant, negative correlation was obtained between BREAK and DEN, indicating that denser kernels (flint type) were less susceptible to physical damage.

The two seed size variables (WT and VOL) were positively correlated. The magnitude of the correlation ($r = .98$) indicates that measuring both traits would be redundant. A significant, negative correlation was obtained between VOL and DEN. Kernels of larger volume were less dense. There was a significant, negative correlation between GRN and DEN and a significant, positive correlation between GRN and DATE. Genotypes that were later and had kernels of lower specific gravity tended to have kernels that had a greater surface area of exposed endosperm. The lack of other significant correlations with DATE may have been caused by the inbreds being selected from the middle of the distribution for days to anthesis, as outlined in Materials and Methods. However, the range for DATE and the highly significant F-test may cause one to question this effect.

Many highly significant correlations were obtained between inbred traits; however, most of these were not high enough to be of strong predictive value. Correlations for BREAK with RATE, WT, VOL, and DEN are high enough to use the latter traits for screening out the poorest material before BREAK data need be taken. The strong correlation between WT and VOL would make measurement of both traits unnecessary.

3. Single-cross plant and grain traits

Mean values and ranges of single crosses for eight plant and grain traits pooled over entries are presented in Table 11. (Mean values for each single-cross entry at each environment are presented in Tables A24 to A33.) The mean value for MOIST was high (22.3%) in the 1976 Ankeny environment and low (14.4%) in the 1978 Atomic Energy environment. Ranges for MOIST were greater in 1976 than in 1978 and 1979. Harvest moisture differences between 1978 and 1979 may have been partial causes for differences in BREAK between the two years. Variations among seasons for MOIST were caused by differences in drying conditions in the fall and the date of harvest. The mean value for BREAK was greatest (13.2%) in 1979 and lowest (4.8%) in 1978. The range was greater in 1976 than in 1978 and 1979. The grain was broken at a higher moisture content (12.5%) in 1978 than in 1976 and 1979 (10%), which was probably the primary cause of these differences.

Seed size, as measured by WT and VOL, was greatest in 1979 (83.6 g and 70.7 ml) and smallest in 1978 (72.6 g and 63.4 ml). The most favorable growing conditions for the single crosses occurred in 1979. Ranges for these traits were greatest in 1976. The kernels from materials grown in 1976 were the densest (1.24 g/ml), as measured by DEN, and the least dense in 1978 (1.14 g/ml). Range for this trait was greatest (1.09-1.39 g/ml) in 1978 and least (1.14-1.26 g/ml) in 1979. Genotypes were later, as measured by DATE, in 1979 (29.3 days) than in 1978 (21.7 days). Ranges for this trait were similar from year to year. The mean values and ranges for RATE were similar from environment to environment, if the different

Table 11. Mean values and ranges of eight plant and grain traits pooled over entries for hybrid tests

Test		Traits							
		MOIST %	RATE[a] 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
1976 Ames	Mean	16.4	3.8	9.5	72.2	58.2	1.24	--------	---------
	Range	11.3-23.3	2.2-5.0	4.2-17.0	53.7-104.9	45.7-86.7	1.17-1.34	--------	---------
1976 Ankeny	Mean	22.3	3.6	14.6	79.1	63.6	1.25	--------	---------
	Range	18.2-27.7	2.2-4.7	8.1-25.0	55.2-115.1	45.3-96.7	1.15-1.38	--------	---------
1976 Combined	Mean	19.3	3.7	12.0	75.6	60.9	1.24	--------	---------
	Range	14.7-23.6	2.2-4.8	6.4-19.4	55.5-110.1	46.0-91.7	1.16-1.32	--------	---------
1978 Ames	Mean	16.9	1.8	4.8	79.4	68.7	1.16	6.9	21.7
	Range	14.2-22.5	1.0-3.0	1.8-11.7	61.5-108.3	55.0-99.0	1.09-1.28	3.8-14.1	19.3-24.7
1978 Atomic Energy	Mean	14.4	1.7	4.7	65.7	58.2	1.13	9.3	---------
	Range	11.7-18.9	1.0-3.0	1.3-10.4	48.4-81.6	42.7-74.0	1.07-1.26	6.4-14.3	---------
1978 Combined	Mean	15.6	1.8	4.8	72.6	63.4	1.14	8.1	21.7
	Range	13.1-20.7	1.0-2.8	2.6-11.1	55.0-94.5	48.8-86.5	1.09-1.39	5.4-13.2	19.3-24.7
1979 Ames	Mean	18.0	2.1	15.4	84.0	71.4	1.18	8.2	29.3
	Range	15.0-23.3	1.0-3.0	11.3-26.5	60.7-103.5	53.3-87.0	1.12-1.27	5.1-11.7	27.0-32.0
1979 Ankeny	Mean	17.2	1.9	11.0	83.2	70.1	1.19	8.8	---------
	Range	15.1-21.4	1.0-3.0	8.0-17.5	74.4-97.8	62.0-78.3	1.13-1.28	6.0-13.1	
1979 Combined	Mean	17.6	2.0	13.2	83.6	70.7	1.18	8.5	29.3
	Range	15.9-21.0	1.0-3.0	10.4-20.8	75.3-100.6	62.0-82.3	1.13-1.23	5.8-12.3	27.0-32.0
Combined	Mean	17.6	2.5	10.1	77.3	65.0	1.19	8.3	25.5
	Range	15.0-21.3	1.4-3.3	6.5-17.1	63.2-99.8	54.8-86.6	1.14-1.26	5.8-12.7	21.3-28.0

[a]Scale 1-5 1976 and 1-3 for 1978 and 1979.

[b]Values were multiplied by 10^2.

rating scale used in 1976 is taken into consideration. The scale of measurement was set relative to the environment. The mean values and ranges for GRN were similar from year to year; however, some location-to-location differences in mean values were observed.

The combined analyses of variance for single crosses presented in Table 12 indicate that highly significant differences among genotypes were observed for all traits. (Analyses of variance for each environment are presented in Tables A34 to A42.) Also, significant genotype x environment interactions were obtained for all traits except DEN and DATE. Examination of single-cross means in Tables A24 to A33 reveals that the significant genotype x environment interactions were probably caused by a change in magnitude rather than a change in rank. Jennings (1974) observed highly significant differences among a fixed set of single crosses for harvest moisture, breakage percentage, 200-K weight, and 200-K volume.

A clearer understanding of the relative importance of the various sources of variation can be determined by examining the magnitude of variance component estimates from the combined analyses of variance for the single crosses. Genotypic (V_G) and genotype x environment (V_{GE}) variances are presented in Table 13. Estimates for V_G were significantly different from zero for all traits. Estimates for V_{GE} were significantly different from zero for all traits, except DEN and DATE. The magnitude of V_G compared to V_{GE} is an important consideration when developing a testing program. The relative size of significant V_{GE} estimates was from 16 percent (RATE) to 41 percent (MOIST) as large as V_G. The magnitude of the V_{GE} estimate for BREAK may have been inflated because of differences in the testing procedure from year to year.

Table 12. Analyses of variance for eight plant and grain traits for 40 hybrid entries, data combined over locations and years

Source d.f.	Mean squares							
	MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Environments (E) (5)[c] 3 [d]{1}[e]	822.15	11214.79	2486.31	5723.77	4113.57	2534.16	120.32	3385.42
Replications/E (12) 8 {4}	7.23	15.34	8.39	55.10	42.05	53.27	16.61	28.72
Genotypes (G) (39) 39 {39}	43.54**	510.11**	86.60**	1067.21**	810.76**	145.23**	27.23**	6.46**
G x E (189) 111 {36}	6.74**	29.99**	11.14**	80.72**	61.01**	29.99	5.95*	1.78
Error[f] (456) 300 {150}	4.26	16.63	6.53	27.89	22.93	29.64	4.39	1.34

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]Degrees of freedom for MOIST, RATE, BREAK, WT, VOL, DEN.

[d]Degrees of freedom for GRN.

[e]Degrees of freedom for DATE.

[f]See Table A43 for error degrees of freedom.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table 13. Genotypic (V_G) and genotype x environment (V_{GE}) variances with standard errors, and error variances for hybrid plant and grain traits, data combined over locations and years

Trait	V_G	V_{GE}	V_e
MOIST	2.00 ± 0.54	0.83 ± 0.25	4.26
RATE[a]	2.67 ± 0.63	0.44 ± 0.11	1.66
BREAK	4.19 ± 1.06	1.54 ± 0.41	6.53
WT	54.80 ± 13.10	17.61 ± 2.82	27.89
VOL	41.65 ± 9.95	12.69 ± 2.14	22.93
DEN[b]	6.40 ± 1.78	0.12 ± 0.74	29.64
GRN[b]	1.77 ± 0.51	0.52 ± 0.33	4.39
DATE[a]	7.80 ± 2.48	1.47 ± 1.47	1.34

[a]Values were multiplied by 10^1.

[b]Values were multiplied by 10^4.

4. Single-cross correlation analyses

Simple and genotypic correlations between pairs of traits for the single crosses were calculated to determine the important relationships among the eight plant and grain traits. These correlation coefficients, calculated for data combined over environments, are presented in Table 14. (Correlation coefficients for each environment are presented in Tables A44 to A52.) Generally, the simple correlation coefficient agrees closely with the genotypic correlation coefficient calculated for each pair of traits. An exception is evident for BREAK with DATE, where the genotypic correlation is much higher than the simple correlation. Differences between the two estimates would be attributed to genotype x environment and error correlations. Further discussion will be based on simple correlation coefficients.

Significant, positive correlations were obtained for MOIST with WT and VOL. The genotypes that had higher grain moisture at harvest had larger kernels. There was a significant, negative correlation between RATE and DEN. The more floury kernel types tended to be less dense.

Significant, positive correlations were obtained for BREAK with WT, VOL, and GRN. The larger kernels were more susceptible to breakage. The correlation between BREAK and GRN ($r = .37$) was larger for the single crosses than for the inbreds probably because data for GRN of the inbreds were taken from only one environment. The significant, negative correlation between BREAK and DEN indicates that less dense kernels were more susceptible to physical damage. These correlations are in close agreement with those obtained by Jennings (1974) for breakage percentage with 200-K weight, 200-K volume, test weight, and seed size.

Table 14. Correlation coefficients between eight plant and grain traits for 40 hybrid entries, data combined over locations and years (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.09	0.21	0.39*	0.42**	-0.13	0.18	0.11
RATE	-0.10		0.27	-0.28	-0.15	-0.59**	0.09	0.00
BREAK	0.24	0.28		0.38*	0.51**	-0.59**	0.37*	0.23
WT	0.41	-0.31	0.39		0.97**	-0.07	-0.16	0.11
VOL	0.44	-0.17	0.52	0.98		-0.23	-0.09	0.12
DEN	-0.16	-0.67	-0.68	-0.02	-0.22		-0.24	-0.10
GRN	0.17	0.11	0.30	-0.16	-0.10	-0.23		0.01
DATE	0.33	0.03	0.74	0.11	0.14	-0.20	0.28	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

The highly significant correlation between WT and VOL indicates that measurement of both traits would be unnecessary. Jennings (1974) calculated correlations between 200-K weight and 200-K volume of similar magnitude. DATE was not correlated with any other variable, which may have been caused by the inbreds being selected from the middle of the distribution for days to anthesis, as outlined in Materials and Methods. However, the range for DATE and the highly significant F-test may cause one to question this effect.

There were fewer significant correlations for the single crosses than for the inbreds. This might be expected if only additive effects were involved because the hybrid values would be midparent values, thus the ranges would be smaller. However, in many cases the size of the correlation was as large for the single crosses but not significant because there were only one-half of the degrees of freedom as there were for the inbreds. The correlation between WT and VOL may be the only correlation of strong predictive value.

5. Inbred-hybrid correlation analyses

Inbred-hybrid correlations were calculated to determine the relationships of inbred traits with similar traits in their hybrid progenies. In a breeding program, it is important to know if traits selected in an inbred parent will be transmitted to its hybrid progenies. All correlations were calculated between the hybrid and mid-parent values.

The correlation coefficients for all paired comparisons, inbred versus single cross, for the eight plant and grain trait data combined over environments are presented in Table 15. (Inbred-hybrid correlations

Table 15. Simple correlation coefficients between the mean of two inbred parents and their hybrid for eight plant and grain traits, data combined over locations and years for 40 hybrids and their parent lines

	Inbred							
	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
Hybrid								
MOIST	0.59**	-0.26	0.22	0.52**	0.42**	0.17	0.15	-0.25
RATE	0.13	0.60**	0.33*	0.02	0.08	-0.26	-0.11	-0.02
BREAK	0.28	0.34*	0.72**	0.53**	0.62**	-0.44**	0.24	-0.02
WT	0.42**	-0.01	0.45**	0.74**	0.74**	-0.03	-0.02	-0.08
VOL	0.43**	0.08	0.54**	0.76**	0.79**	-0.16	0.02	-0.08
DEN	-0.07	-0.42**	-0.46**	-0.16	-0.29	0.64**	-0.20	-0.04
GRN	-0.09	0.24	0.05	0.06	0.10	-0.28	0.54**	0.02
DATE	0.30	-0.04	0.16	0.08	0.08	-0.02	-0.11	0.14

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

for each environment are presented in Tables A53 to A58.) The expression of MOIST, RATE, BREAK, WT, VOL, DEN, and GRN in the inbred parents gave a fairly good indication of the expression of the same traits in their hybrid progenies. These significant correlations ranged from r = 0.54 for GRN to r = 0.79 for VOL. The fairly high trait-to-trait correlations are in close agreement with those reported by Balko and Russell (1980), and were much higher than those reported by Gama and Hallauer (1977) for various other traits in BSSS.

Inbred MOIST was positively correlated with hybrid seed size (WT and VOL). Inbred RATE was positively correlated with hybrid BREAK and negatively correlated with hybrid DEN; therefore, visual rating in parent material may be of some use in screening for breakage resistance and seed type in hybrid combination.

There were significant, positive correlations between inbred BREAK and hybrid RATE, WT, and VOL and a significant, negative correlation with hybrid DEN. The more breakage-resistant inbreds will tend to produce hybrids with small, dense, flinty kernels.

Inbred WT and VOL were positively correlated with hybrid MOIST, BREAK, and with one another. Thus, inbreds with large kernels will tend to produce hybrids with large kernels, later maturity, and more susceptibility to breakage. A significant, negative correlation was obtained between inbred DEN and hybrid BREAK; consequently, inbreds selected for a dense kernel type will produce breakage-resistant hybrids.

Inbred GRN was correlated with only hybrid GRN. Evidently, the only means of selecting for hybrids that have low surface area of exposed endosperm is to select for the same trait in the inbred parent. Neither inbred nor hybrid DATE was correlated with any trait, which again may have been caused by the choice of the experimental material.

Although these correlations may not be high enough to be of strong predictive value, plotting inbred means versus hybrid means for various trait combinations may provide a clearer understanding of the relationships. The plot of inbred BREAK versus hybrid BREAK (Figure 3) reveals that selection against breakage in inbred parents will eliminate most of the breakage-susceptible hybrids. The same type of relationship is evident in the plot of inbred RATE versus hybrid RATE (Figure 4); therefore, the desired kernel type in hybrid combination probably can be selected during inbred development. Even though the correlation between inbred RATE and hybrid BREAK is not of strong predictive value, Figure 5 shows that selecting inbreds with a visual rating below 2.5 will eliminate the majority of the more breakage-susceptible hybrids. The same relationship exists for inbred WT and hybrid BREAK (Figure 6); thus, selecting against large seeded inbreds would be useful as a screening device provided potential yield loss from selecting smaller seeded genotypes could be minimized. In all four diagrams, the few extreme values or correlation breakers could have contributed disproportionately to the correlation. Thus, without these exceptional points the correlations may have been larger.

6. Selection indices

Several selection indices (Table 6) were formed to determine the most efficient method of selecting for breakage resistance. The restricted

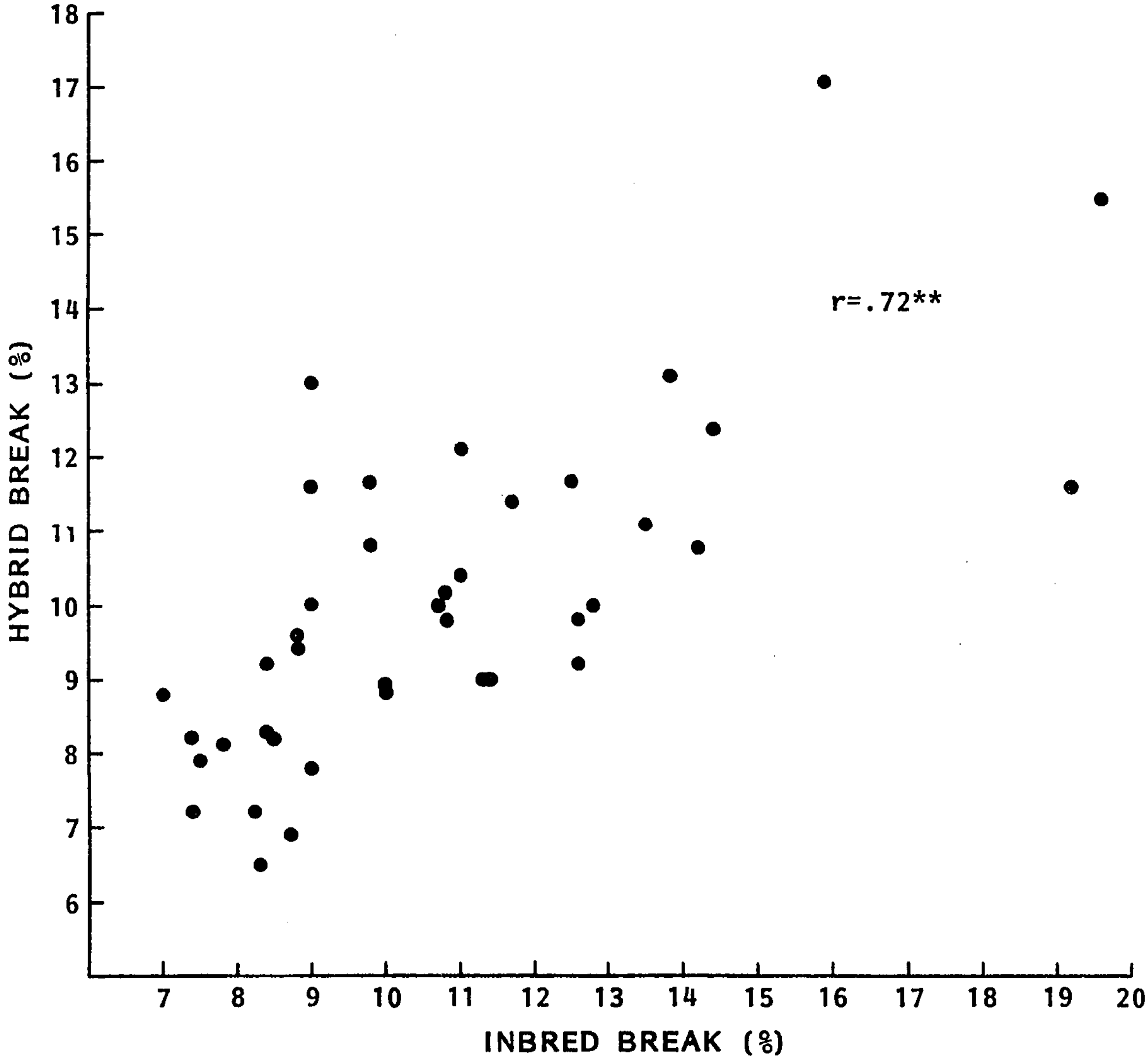

Figure 3. BREAK mean values, hybrid vs. inbred midparent

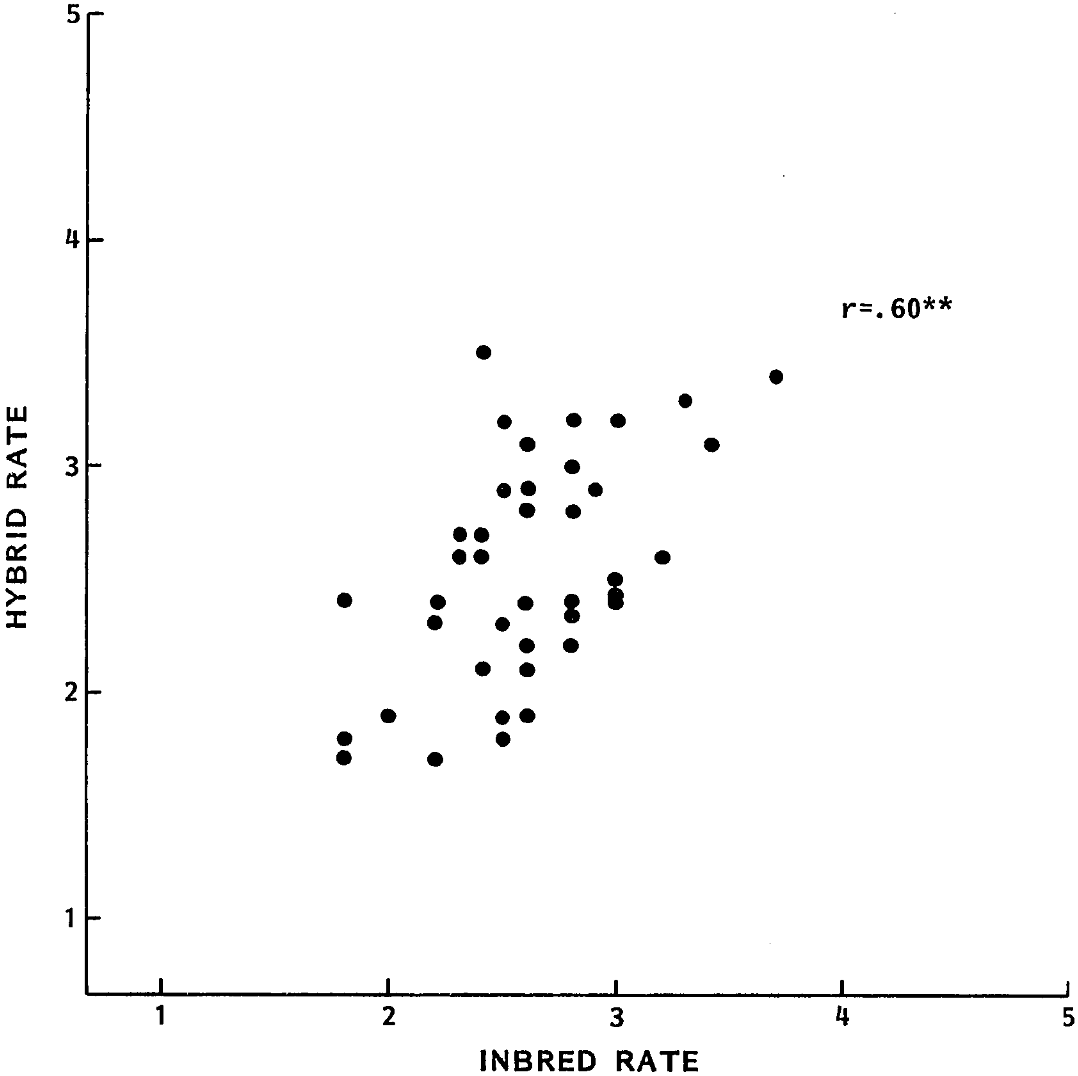

Figure 4. RATE mean values, hybrid vs. inbred midparent

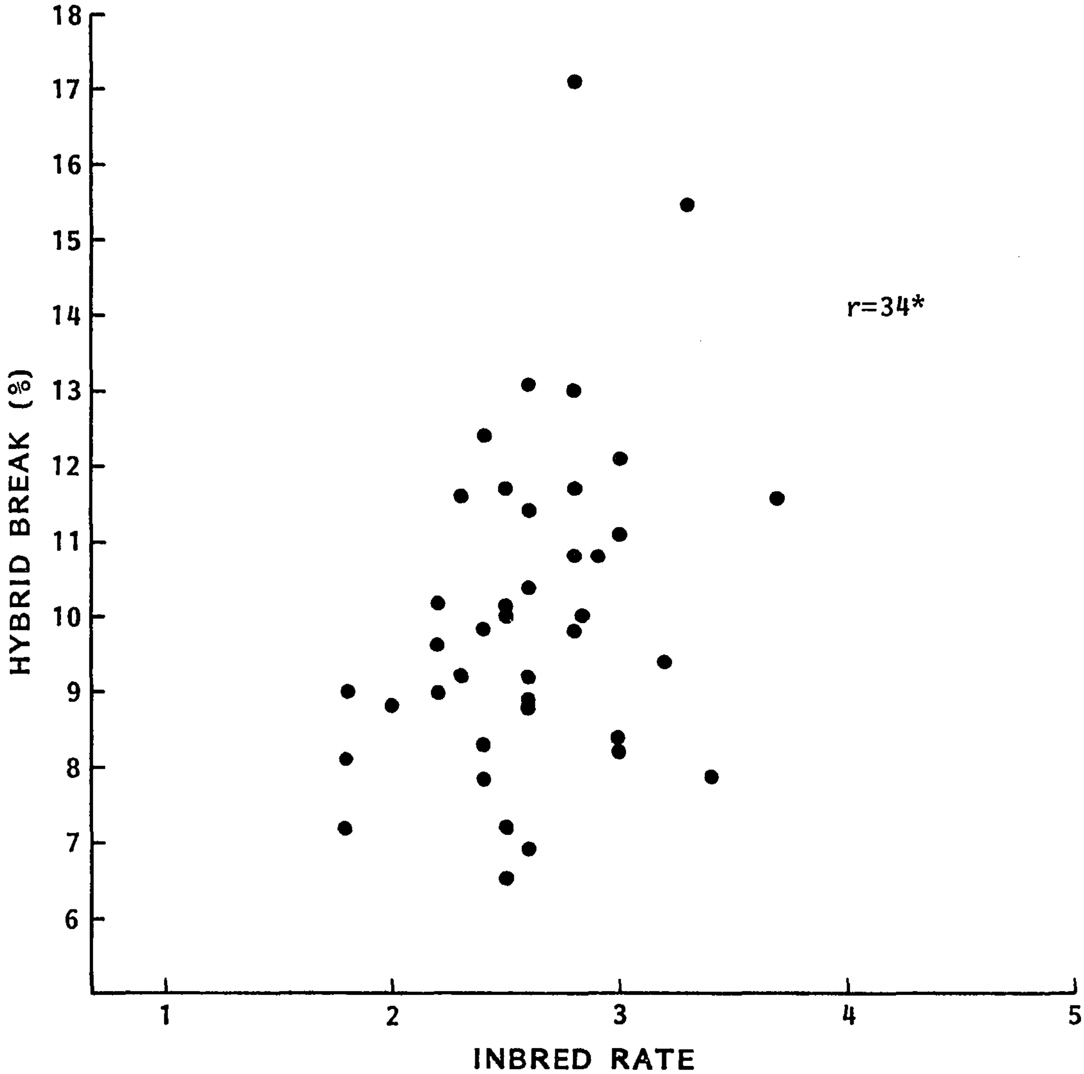

Figure 5. Inbred midparent RATE vs. hybrid BREAK means

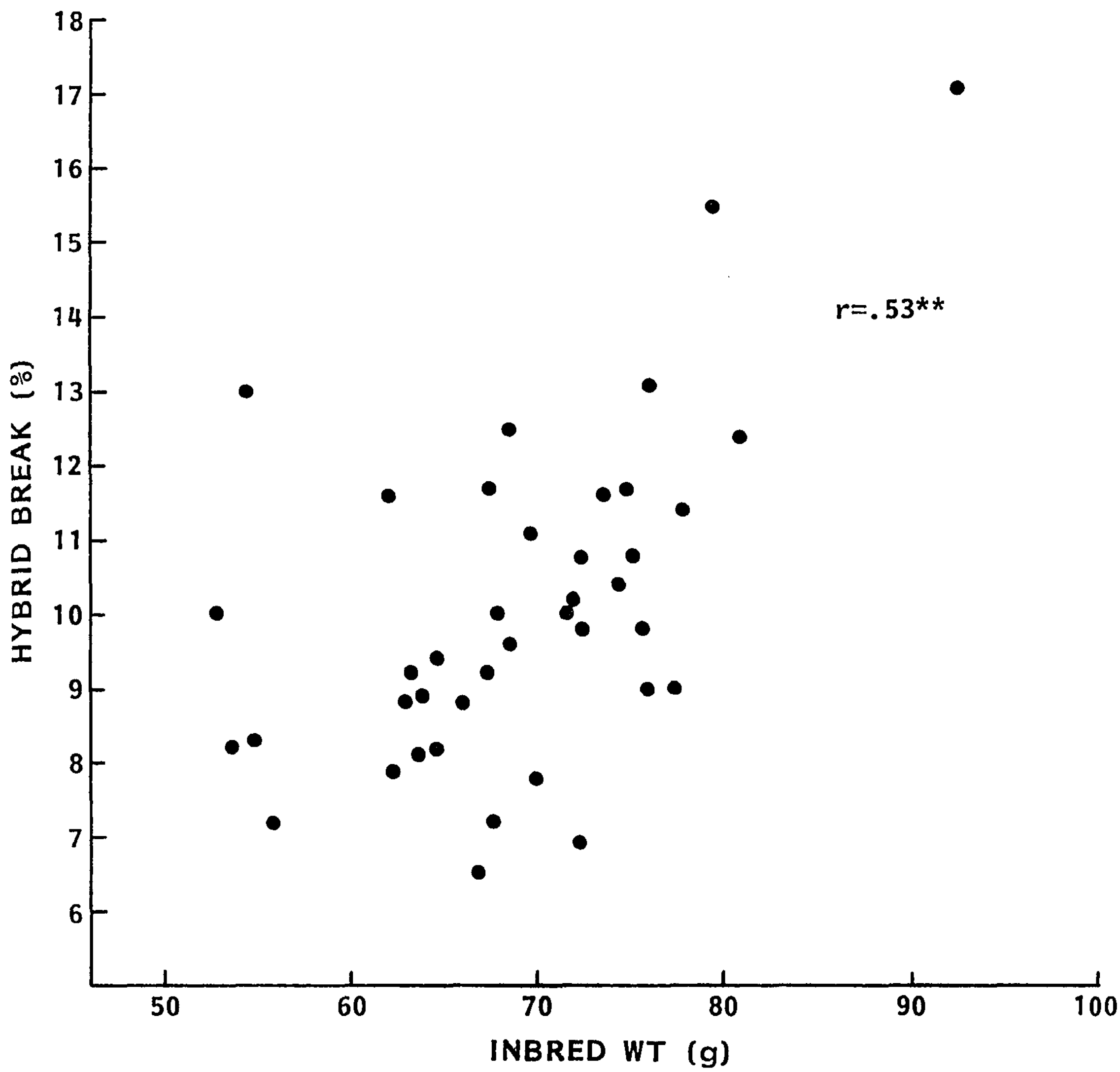

Figure 6. Inbred midparent WT means vs. hybrid BREAK means

indices, R1 and R2, were the ultimate methods of selection because they could control gain on several traits simultaneously. Undesirable correlations, such as seed size (WT and VOL) with BREAK, made it necessary to restrict changes in seed size caused by selection for breakage resistance. All comparisons of indices should be made with R1 or R2 as the standard. The plant breeder would like to know if the Elston's weight-free indices or the rank summation indices would select similar lines as would be selected by the restricted indices. The restricted indices are much more difficult to construct and the weights for each trait (Table A59) are applicable only to BSSS.

The inbreds were ranked based on all 16 indices and the rankings were compared with Spearman rank correlation coefficients presented in Table 16. The correlation between R1 and R2 was highly significnat (r = .99), thus comparisons will be made only to R1 as the standard. Also, correlations between Elston indices and rank summation indices that included the same traits were very high (i.e. E1 and RS1, r = .92); therefore, only the rank summation indices will be discussed because the calculations for these indices are less involved than those for the Elston indices.

All of the rank summation indices were highly significantly correlated with R1. RS1 had the highest correlation (r = .65) and RS7 had the lowest correlation (r = .29) with R1. The correlations for RS1, RS2, RS3, and RS5 with R1 were all of similar magnitude; therefore, RS5 would be the most efficient method because only one trait need be measured (BREAK). These correlations for RS1, RS2, RS3, and RS5 are high enough that a group

Table 16. Spearman rank correlation coefficients for 16 grain quality indices

	E2	E3	E4	E5	E6	E7	R1	R2	RS1	RS2	RS3	RS4	RS5	RS6	RS7
E1	0.80**	0.80**	0.84**	0.58**	0.55**	0.62**	0.60**	0.61**	0.92**	0.77**	0.79**	0.79**	0.58**	0.55**	0.62**
E2		0.52**	0.54**	0.73**	0.67**	0.12	0.59**	0.61**	0.78**	0.95**	0.54**	0.55**	0.73**	0.67**	0.12
E3			0.54**	0.74**	0.10	0.74**	0.56**	0.58**	0.79**	0.52**	0.98**	0.53**	0.74**	0.10	0.74**
E4				0.13	0.67**	0.72**	0.41**	0.42**	0.79**	0.57**	0.53**	0.93**	0.13	0.67**	0.72**
E5					0.12	0.17	0.60**	0.62**	0.62**	0.72**	0.78**	0.15	1.00**	0.12	0.17
E6						0.11	0.38**	0.39**	0.63**	0.75**	0.12	0.76**	0.12	1.00**	0.11
E7							0.30**	0.30**	0.64**	0.17	0.74**	0.72**	0.17	0.11	1.00**
R1								0.99**	0.65**	0.64**	0.60**	0.46**	0.60**	0.38**	0.29**
R2									0.67**	0.65**	0.61**	0.47**	0.62**	0.39**	0.30**
RS1										0.85**	0.83**	0.85**	0.63**	0.63**	0.64**
RS2											0.57**	0.64**	0.72**	0.76**	0.17
RS3												0.55**	0.78**	0.12	0.74**
RS4													0.15	0.76**	0.72**
RS5														0.12	0.17
RS6															0.11

** Significant to the 0.01 level of probability.

of inbreds selected with these indices probably would be similar to a group of inbreds selected with R1. However, correlations between and among RS1, RS2, RS3, and RS5 were not much greater than with R1, thus identical rankings were not made.

To determine the effect of selection with each index on all of the eight plant and grain traits, selection differentials were calculated for each index. The mean value for each trait of the top 20 percent of the inbreds based on each index was subtracted from the mean value for each trait of the whole population of inbreds to obtain the selection differentials presented in Table 17. Again for the reasons stated earlier, only the indices R1, RS1, RS2, RS3, and RS5 will be discussed. R1 was the standard index with selection differentials showing genotype means with greater seed size (WT and VOL), less physical damage (BREAK and GRN), earlier anthesis (DATE), more flinty kernel type (RATE), and less moisture at harvest (MOIST) than the population means. Fast dry-down in the fall is ordinarily a desirable feature in inbred lines; therefore, selection for breakage resistance would be complementary. The other indices showed the same trends, except for the great reduction in WT and VOL. Selection for BREAK alone (RS5) had the greatest selection differential for BREAK (-4.2%), but also for WT and VOL (-10.0 g and -9.4 ml). These undesirable correlated responses may deem restricted indices essential for selection of breakage resistance. Because no yield data were taken, the effect on yield is unknown, but with a reduction in seed size and a more flinty kernel type yield reductions may be expected. However, Jennings (1974) found no correlation between breakage resistance and yield.

Table 17. Selection differentials of 16 grain quality indices for eight inbred plant and grain traits

Index	Selection differential[a]							
	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
E1	-0.9	-0.5	-2.5	-2.2	-3.4	0.04	-2.5	-1.4
E2	-1.6	-0.5	-2.8	-5.3	-5.6	0.03	-0.6	-1.0
E3	-1.1	-0.2	-2.9	-3.6	-4.1	0.02	-2.9	-0.9
E4	-0.5	-0.6	-1.7	-2.4	-3.3	0.02	-2.2	-1.5
E5	-2.5	0.1	-4.2	-10.0	-9.4	0.03	-0.6	-1.2
E6	0.1	-0.8	-0.9	-2.0	-2.7	0.02	-0.6	-0.5
E7	-0.4	-0.2	-1.1	1.7	0.6	0.02	-3.4	-0.2
R1	0.7	-0.3	-2.5	5.3	2.9	0.03	-0.7	-1.2
R2	0.7	-0.3	-2.5	5.3	2.9	0.03	-0.7	-1.2
RS1	-1.2	-0.5	-2.9	-5.1	-5.9	0.04	-2.3	-1.5
RS2	-1.4	-0.6	-3.1	-6.0	-6.9	0.05	-1.6	-1.4
RS3	-1.7	-0.2	-3.2	-4.1	-4.6	0.03	-2.6	-1.3
RS4	-0.7	-0.6	-2.0	-1.0	-2.2	0.03	-2.5	-1.2
RS5	-2.5	0.1	-4.2	-10.0	-9.4	0.03	-0.6	-1.2
RS6	0.1	-0.8	-0.9	-2.0	-2.7	0.02	-0.6	-0.5
RS7	-0.5	-0.2	-1.1	1.7	0.6	0.02	-3.4	-0.2

[a]S.D. = top 20% of pop'n-whole pop'n.

[b]Values were multiplied by 10^2.

B. General Discussion

The highly significant differences among random inbred genotypes determined from the analyses of variance indicated that there is variability present in BSSS for all eight plant and grain traits. The traits BREAK and GRN were of particular interest because they measured physical damage susceptibility. The heritability estimates indicated that all traits except DEN are very heritable on a entry-mean basis. Thus, the genetic variability and heritability present in BSSS should make progress from selection possible for any trait, with the possible exception of DEN.

The magnitude of the genotype x environment interaction relative to the main effect was of interest to determine the extent of testing necessary for a breakage-resistance selection program. The estimated genotype x environment variance component was usually 25 to 50 percent of the magnitude of the estimated genotypic variance component. Also on examination of the means, changes in magnitude rather than changes in rank, appeared to be the primary cause of genotype x environment interaction which may cause the plant breeder to select the wrong lines. For all traits that were measured, a limited number of environments would be necessary. In many instances, the combined analyses of variance over locations in a given year revealed no significant genotype x location interaction; therefore, year-to-year variations were probably of more importance, and testing in one location over two years may be adequate. For the traits RATE, GRN, and DATE single-cross data indicated that evaluation in one environment may be adequate.

The *per se* inbred and single-cross correlation analyses revealed which relationships were of importance. The very high correlations between WT and VOL indicated only one trait need be measured, probably WT because these measurements can be made more accurately. Genotypes that had less breakage percentage tended to be drier at harvest and to have small, flinty, dense kernels. GRN and BREAK were significantly correlated, but correlations were low. Evidently, the two traits were measuring different things. GRN measured the area of exposed endosperm that may lead to grain deterioration, while BREAK measured the fine material produced from impelling. GRN may be more repeatable than BREAK because GRN does not have the moisture interaction problem that BREAK has, has a smaller genotype x environment interaction than BREAK, and requires less costly equipment for measurement than does BREAK. However, BREAK showed more significant correlations with other traits, and with my techniques, BREAK data could be taken more rapidly. The correlation for MOIST with BREAK and GRN indicated that wetter corn at harvest is more prone to combine damage. Maturity, as measured by DATE, does not appear to be of major concern regarding breakage resistance, but the manner in which the genotypes were chosen for this study may have affected potential relationships.

The inbred-hybrid correlations that were obtained estimated the transmittal of a trait from inbred parent to hybrid progenies. The relatively high trait-to-trait correlations indicated a reasonable chance that a selected trait in an inbred will be expressed in hybrid combination. The correlations between inbred RATE, WT, and VOL and hybrid BREAK revealed that these inbred traits may be useful for screening out the poorest material early in the inbred development process. RATE is particularly appealing because the data can be taken rapidly and in the field. Whereas, there may be some concern that selection for the hard starch (flinty) type kernel would mean selection for small seed (e.g. popcorn as an extreme), the correlation results show no relationship between endosperm type and seed size or weight in dent corn. There appears to be no way to select for hybrid GRN except to select for inbred GRN.

The undesirable correlated responses between seed size and BREAK may make the use of restricted indices necessary. The main disadvantages to this procedure are the complicated computations required, and the plant breeder must have the necessary phenotypic and genotypic variance and covariance estimates for each population in a breeding program. The rank summation indices are the easiest to calculate and may be useful if one is willing to accept smaller seeded genotypes. What effect selection for breakage resistance will have on yield can not be determined from this study. Kernel hardness is probably relatively simply inherited; therefore, another possibility would be a tandom selection program. Several cycles of recurrent selection for breakage resistance could be carried out until an acceptable gene frequency for favorable alleles for this trait is reached, followed by recurrent selection for yield. During the breakage-resistance selection phase, some selection pressure to maintain seed size may be necessary. Russell and Machado (1978) found 300-K weight in the inbreds to be the best predictor of hybrid grain yield.

The main limitation to inferences from this study is that the results may be applicable only to BSSS. The manner in which experimental materials were chosen may have affected the results regarding DATE. The inbred data for GRN and DATE were collected from only one environment; therefore, the effect of the genotype x environment interaction is unknown. The inbreds were unselected for vigor, thus they were inhibited by any stress. Also, the missing plots in every inbred test may have an effect on the results. This was not a problem for the single crosses, and the six environments for the single-cross evaluations probably gave a thorough test.

The obvious future research need is to determine the effect of selection for breakage resistance on grain yield. If grain yield is not affected greatly, rapid progress for breakage resistance could be expected without this limitation. Also, more data for GRN and DATE for the inbreds used in this study would provide a clearer understanding of genotype x environment interactions and of the value of these measurements for a breakage-resistance selection program.

V. SUMMARY

The amount and percentage of physically damaged corn have become ever increasing problems. Poor market quality corn is expensive to the farmer-producer, the warehouseman, the consumer, and society. Agricultural engineers have put considerable effort into improving the harvest combine, drying facilities, and loading operations to decrease physical damage to corn. Efforts to improve market quality of corn via genotype modification have been minimal because the genetics of physical grain quality traits have not been investigated. The objective of this research project was to determine the potential for selection of superior breakage-resistant genotypes.

Eighty random inbred lines derived from BSSS and 40 single crosses developed from these inbreds constituted the genetic material. The materials were grown in the crop years of 1976, 1977, 1978, and 1979. The Agronomy Research Station near Ames, Iowa was one location for each of the years. In 1976, 1977, and 1979, the I.S.U. Research Farm near Ankeny, Iowa and the farm at the Federal Atomic Energy Research Plant near Ames in 1978 were the second locations. In 1977, no materials were harvested because of severe drought. Only limited analyses were possible for the 1978 Atomic Energy inbred test because of low grain yield caused by severe European corn borer infestation. In 1979, the inbred test at Ankeny was not harvested because of poor seed set and the inbred test at Ames was not analyzed because of a derandomization problem.

The experimental field design was a randomized complete block with three replications at each location. The experimental unit was a three-row plot in which one row was hand picked to obtain ears for visual rating of endosperm type and the remaining two rows were combined harvested to obtain grain samples for the laboratory analyses. Data were collected in each environment for harvest moisture, visual rating, breakage percentage, kernel weight, kernel volume, and specific gravity. In 1978 and 1979, data were taken for the Fast Green dye test and days to anthesis.

The analyses of variance revealed highly significant differences among, both inbred and single-cross, genotypes for all traits. Significant genotype x environment interactions were obtained for all traits, except specific gravity and days to anthesis. For the inbreds, no genotype x environment interaction estimates were available for the Fast Green dye test and days to anthesis because data were taken in only one environment. The relative size of the estimated genotype x environment variance component for each trait was from 16 to 58 percent as large as the estimated genotypic variance component. Progeny-mean heritability estimates were relatively large (76-87%), except for specific gravity (39%). Thus, from these analyses it was determined that there is genetic variability for the eight plant and grain traits in BSSS and the traits were relatively highly heritable, except for specific gravity. Genotype x environment interactions were present, but evaluation in one environment may be adequate for visual rating, the Fast Green dye test, and days to anthesis. For the remaining traits, evaluation at one location for two years may be adequate.

Correlation analyses, for both the inbreds and single crosses, revealed a strong interdependence among some grain characters, i.e., percentage breakage with harvest moisture, visual rating, kernel weight and volume, specific gravity, and the Fast Green dye test for both the inbreds and hybrids. These correlations may not be of strong predictive value, but at least the more breakage-susceptible material may be eliminated on the basis of endosperm type and seed size. The correlation between percentage breakage and the Fast Green dye test were not as high as was expected evidently because the two tests were measuring physical damage differently. The strong correlation between kernel weight and kernel volume indicated that measurement of both traits would be unnecessary. Because of the absence of a correlation between breakage resistance and days to anthesis, maturity does not seem to be an obstacle in a selection program for breakage resistance. Inbred-hybrid correlations were calculated to determine the transmittal of traits from inbred parent to hybrid progenies. The relatively large trait-to-trait correlations for all traits, except for days to anthesis, indicated that expression in inbred parents gave a fairly good indication of expression of the same traits in their hybrid progenies. Inbred kernel weight, kernel volume, and visual rating were significantly correlated with hybrid breakage percentage. Thus, selection against large-seeded, floury kernel-type inbreds may be a useful screening device to eliminate the more breakage-susceptible material early in the inbred development process provided potential yield loss from smaller kernel types could be controlled. Whereas there may be some concern that selection for the hard starch (flinty) type kernel would mean selection for small seed (e.g. popcorn as an extreme), the correlation results showed no relationship between endosperm type and seed size or weight in dent corn.

Rank summation Elston's weight-free, and restricted indices were calculated to determine the most efficient method for selection for breakage resistance. The inbreds were ranked with each index and the ranks were correlated with Spearman rank correlations. The restricted indices would be able to control loss of seed size from breakage-resistance selection, but these indices have the disadvantage of being complicated and of requiring considerable information. The rank summation and the Elston indices showed similar highly significant correlations with the restricted indices; therefore, the rank summation indices would be the best alternative to the restricted indices because of their ease of calculation. Selection differentials were calculated for each index, and it was determined that seed size losses resulting from selection with the rank summation and the Elston indices may be unacceptable. As an alternative to index selection, tandom selection was proposed.

The results obtained from this study are applicable only to BSSS and in environments similar to the environments of the tests. The major future research need is to determine the effect that breakage-resistance selection has on grain yield. Final worth of an inbred line for breakage-resistance must be determined in hybrid combination.

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VIII. APPENDIX

Table A1. Listings of inbred plant materials

Entry number	Pedigree number (SSS-)	Entry number	Pedigree number (SSS-)
1	200	41	116
2	038	42	209
3	111	43	249
4	152	44	092
5	237	45	039
6	172	46	239
7	162	47	112
8	054	48	167
9	206	49	129
10	073	50	227
11	202	51	163
12	165	52	216
13	125	53	063
14	106	54	051
15	103	55	013
16	211	56	059
17	091	57	161
18	191	58	089
19	037	59	056
20	007	60	238
21	030	61	036
22	126	62	232
23	235	63	055
24	069	64	114
25	043	65	150
26	135	66	148
27	102	67	096
28	141	68	158
29	041	69	170
30	132	70	230
31	020	71	028
32	011	72	214
33	074	73	159
34	084	74	117
35	040	75	234
36	027	76	123
37	099	77	044
38	134	78	042
39	187	79	240
40	204	80	143

Table A2. Listings of hybrid plant materials

Entry number	Pedigree number (SSS-)	Entry number	Pedigree number (SSS-)
81	200 x 038	101	116 x 209
82	111 x 152	102	249 x 092
83	237 x 172	103	039 x 239
84	162 x 054	104	112 x 167
85	206 x 073	105	129 x 227
86	202 x 165	106	163 x 216
87	125 x 106	107	063 x 051
88	103 x 211	108	013 x 059
89	091 x 191	109	161 x 089
90	037 x 007	110	056 x 238
91	030 x 126	111	036 x 232
92	235 x 069	112	055 x 114
93	043 x 135	113	150 x 148
94	102 x 141	114	096 x 158
95	041 x 132	115	170 x 230
96	020 x 011	116	028 x 214
97	074 x 084	117	159 x 117
98	040 x 027	118	234 x 123
99	099 x 134	119	044 x 042
100	187 x 204	120	240 x 143

Table A3. Mean values of 80 inbred entries for six grain traits at Ames in 1976

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
1	14.5	2.8	4.8	67.8	54.7	1.24
2	22.1	4.8	9.8	48.4	43.5	1.11
3	21.6	2.2	8.3	87.7	70.0	1.26
4	16.9	2.7	7.9	44.6	36.0	1.25
5	12.6	3.0	8.4	67.1	55.0	1.22
6	16.2	3.0	19.4	70.9	59.7	1.19
7	18.5	2.8	11.0	80.1	66.7	1.20
8	21.1	2.0	14.0	50.8	41.3	1.23
9	18.5	2.2	12.9	71.0	57.3	1.24
10	23.4	1.7	10.3	76.9	57.7	1.35
11	12.4	1.3	4.2	42.8	32.3	1.32
12	15.6	3.0	10.3	56.4	46.5	1.21
13	17.4	3.5	9.6	60.1	48.7	1.24
14	16.3	2.3	13.7	72.6	59.3	1.22
15	10.4	1.8	11.3	55.9	43.7	1.28
16	25.5	3.0	10.9	65.8	53.3	1.24
17	17.1	1.8	6.0	50.2	43.3	1.16
18	21.9	2.8	11.0	67.0	53.3	1.26
19	13.8	3.0	8.8	88.8	72.7	1.22
20	13.4	2.2	9.5	41.8	38.0	1.10
21	11.0	3.3	8.1	48.9	43.0	1.13
22	15.5	2.5	9.9	50.4	39.5	1.28
23	17.4	3.5	9.6	60.1	48.7	1.24
24	16.9	3.0	14.6	73.6	63.3	1.16
25	8.1	3.0	12.6	51.9	46.7	1.11
26	8.1	3.3	6.5	46.3	38.0	1.22
27	24.4	3.0	10.6	83.3	68.7	1.21
28	7.7	1.2	8.5	45.8	35.0	1.31
29	23.3	2.8	13.7	64.8	51.0	1.27
30	21.2	3.5	9.1	66.5	57.0	1.18
31	22.6	3.0	13.2	81.2	66.0	1.23
32	13.9	2.3	6.2	61.6	49.0	1.26
33	24.8	3.0	10.0	85.9	69.7	1.23
34	23.8	2.0	12.8	63.2	51.7	1.22
35	13.9	3.0	8.2	79.4	64.7	1.23
36	20.3	2.8	8.7	62.1	49.3	1.26
37	16.4	3.0	8.6	61.6	51.5	1.20
38	19.5	3.0	12.9	69.4	59.0	1.17
39	12.7	2.3	7.9	59.4	47.7	1.25
40	11.9	3.0	8.5	60.2	49.3	1.22
Mean	17.7	2.7	10.8	64.8	53.1	1.22
$LSD_{(.05)}$	6.3	0.6	4.1	10.6	9.1	0.08

Table A3 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
41	23.1	3.0	12.6	76.0	60.0	1.27
42	14.1	2.5	17.0	74.3	62.3	1.19
43	18.4	3.0	15.5	73.0	58.3	1.26
44	12.8	2.2	7.5	61.4	49.3	1.24
45	16.3	3.0	7.3	59.1	47.7	1.24
46	15.7	3.8	10.0	67.9	56.0	1.21
47	30.9	3.0	17.0	79.6	61.3	1.32
48	12.6	3.8	25.0	82.9	75.5	1.10
49	23.4	1.5	12.2	71.4	56.5	1.27
50	25.8	2.8	13.7	65.4	56.0	1.16
51	14.6	3.0	9.5	69.0	57.5	1.20
52	17.7	3.0	10.6	61.2	52.0	1.18
53	16.6	1.3	7.1	43.6	38.0	1.15
54	15.0	3.2	5.7	66.2	55.0	1.20
55	18.4	2.0	12.0	52.3	41.3	1.27
56	22.2	3.0	19.3	97.7	78.0	1.26
57	15.0	2.2	4.7	60.9	49.3	1.24
58	14.3	1.8	8.8	62.0	50.3	1.23
59	24.3	1.7	10.3	64.7	50.7	1.28
60	11.7	3.0	10.3	60.4	48.7	1.24
61	11.5	2.2	8.1	41.0	33.0	1.24
62	9.9	3.8	4.6	43.4	37.3	1.16
63	13.0	2.0	6.2	67.1	57.0	1.18
64	16.9	2.0	5.3	52.0	41.3	1.26
65	14.5	1.8	6.8	43.1	36.0	1.20
66	25.9	3.7	9.1	61.2	52.0	1.17
67	21.0	2.3	11.6	78.5	63.3	1.24
68	16.4	2.3	10.9	69.0	54.0	1.28
69	21.3	2.7	7.7	67.2	54.7	1.23
70	15.0	3.0	9.5	64.5	56.0	1.15
71	22.7	3.0	12.4	78.8	63.3	1.24
72	11.5	3.0	8.7	65.2	52.7	1.24
73	20.2	3.0	16.5	72.5	61.3	1.18
74	21.8	2.0	11.0	63.6	51.0	1.25
75	11.9	2.5	8.2	51.8	43.0	1.20
76	27.6	3.0	9.5	74.0	58.7	1.26
77	24.6	5.0	40.4	63.1	60.0	1.05
78	17.4	2.8	12.6	75.6	60.3	1.25
79	19.9	2.5	10.5	81.8	65.5	1.25
80	21.9	2.8	16.6	87.7	76.0	1.15
Mean	17.7	2.7	10.8	64.8	53.1	1.22
$LSD_{(.05)}$	6.3	0.6	4.1	10.6	9.1	0.08

Table A4. Mean values of 80 inbred entries for six grain traits at Ankeny in 1976

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
1	20.2	2.8	10.8	76.8	56.3	1.36
2	25.1	4.2	16.9	58.3	47.7	1.22
3	24.3	2.2	14.4	90.6	69.0	1.31
4	24.2	2.8	12.6	53.4	42.0	1.27
5	18.3	3.2	10.8	69.0	54.0	1.28
6	19.1	3.0	33.4	73.4	66.3	1.11
7	23.0	3.0	17.6	94.4	76.7	1.23
8	23.9	2.0	13.9	65.4	49.0	1.33
9	27.1	1.8	25.1	80.5	65.3	1.24
10	29.2	2.0	15.7	82.3	62.3	1.32
11	20.0	2.0	8.5	51.4	37.0	1.39
12	22.9	2.8	13.4	75.0	57.7	1.30
13	30.3	3.0	19.9	69.4	54.0	1.29
14	21.7	3.3	15.2	80.9	63.3	1.28
15	18.9	1.7	16.3	62.1	46.7	1.33
16	28.0	2.5	19.0	70.7	55.0	1.28
17	19.9	2.3	13.5	63.2	48.7	1.30
18	27.7	2.7	14.4	73.7	54.0	1.36
19	23.8	2.8	13.8	94.9	74.7	1.27
20	21.9	2.3	17.3	63.5	51.7	1.24
21	16.9	3.0	12.8	52.6	42.3	1.24
22	24.4	2.3	13.0	51.6	37.3	1.38
23	22.2	3.3	18.1	77.7	60.0	1.30
24	23.6	3.0	19.1	79.2	65.0	1.22
25	14.5	3.2	20.4	60.9	52.0	1.18
26	17.3	3.2	11.2	50.8	40.0	1.27
27	31.6	3.0	18.7	106.9	83.7	1.28
28	16.9	2.0	12.3	57.0	42.0	1.36
29	29.6	2.7	17.5	69.7	52.3	1.33
30	25.6	2.8	14.5	80.2	61.7	1.30
31	22.2	3.0	16.8	86.5	67.0	1.29
32	17.7	2.8	6.7	58.1	43.3	1.34
33	30.0	2.7	17.8	80.9	73.7	1.24
34	30.4	2.0	24.1	70.9	54.5	1.30
35	22.3	3.0	17.6	88.6	68.0	1.31
36	23.7	3.0	11.7	66.6	49.3	1.35
37	18.8	3.0	10.5	63.1	51.0	1.24
38	19.2	3.0	10.2	72.2	57.3	1.26
39	19.8	2.7	11.3	76.4	57.7	1.33
40	19.7	3.0	9.6	76.4	59.0	1.30
Mean	23.3	2.8	16.7	74.6	58.5	1.28
$LSD_{(.05)}$	3.2	0.5	4.2	8.6	8.2	0.09

Table A4 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
41	30.2	3.2	19.3	86.3	66.7	1.30
42	23.1	2.8	15.5	91.6	70.7	1.30
43	26.0	2.7	25.5	76.2	61.0	1.25
44	21.5	2.0	12.9	74.4	57.0	1.31
45	21.7	3.2	13.0	69.2	53.3	1.30
46	25.2	3.7	16.5	72.9	59.7	1.23
47	33.4	2.7	23.4	85.9	67.3	1.28
48	18.6	4.0	36.1	81.4	70.7	1.16
49	25.1	2.2	16.4	75.2	59.7	1.26
50	30.1	3.0	23.0	95.5	77.7	1.23
51	19.5	3.0	14.7	75.0	60.0	1.24
52	24.4	3.3	21.6	67.0	55.3	1.21
53	25.3	2.2	21.1	69.8	57.0	1.23
54	21.6	3.2	10.8	68.9	53.7	1.28
55	22.0	2.0	16.7	63.9	48.7	1.32
56	23.6	3.3	26.0	98.4	78.7	1.25
57	21.0	2.0	12.5	80.0	64.0	1.25
58	22.3	1.7	15.9	74.2	56.0	1.33
59	20.9	2.0	17.5	85.0	69.0	1.23
60	22.0	3.2	15.2	78.5	61.7	1.27
61	22.3	2.5	14.6	72.4	55.7	1.30
62	17.8	4.0	10.4	51.9	42.0	1.23
63	19.9	1.7	15.5	79.3	63.7	1.25
64	22.3	1.8	9.6	59.5	43.0	1.39
65	16.9	2.0	11.1	59.6	43.7	1.37
66	23.6	4.0	14.3	58.6	47.0	1.26
67	27.2	2.8	18.7	91.7	72.0	1.27
68	22.6	2.2	16.3	83.6	63.0	1.33
69	28.5	3.0	15.2	76.4	58.0	1.32
70	22.0	3.2	16.6	86.2	71.7	1.20
71	25.7	2.8	20.1	84.8	67.3	1.26
72	21.4	2.8	13.4	67.2	49.0	1.37
73	22.8	3.2	23.6	69.5	56.3	1.24
74	27.1	2.5	15.4	69.5	50.7	1.37
75	17.8	2.7	11.2	59.8	45.3	1.32
76	28.2	2.5	14.7	79.8	57.7	1.40
77	28.0	4.8	34.5	80.0	71.0	1.13
78	24.9	2.8	20.3	85.4	68.0	1.26
79	26.4	2.8	20.6	99.6	79.0	1.26
80	25.4	2.8	27.6	102.7	84.7	1.22
Mean	23.3	2.8	16.7	74.6	58.5	1.28
$LSD_{(.05)}$	3.2	0.5	4.2	8.6	8.2	0.09

Table A5. Mean values of 80 inbred entries for six grain traits data combined over two locations in 1976

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
1	17.4	2.8	7.8	72.3	55.5	1.30
2	23.6	4.4	13.4	54.4	46.0	1.18
3	23.0	2.2	11.4	89.1	69.5	1.28
4	20.6	2.8	10.2	49.0	39.0	1.26
5	15.5	3.1	9.6	68.0	54.5	1.25
6	17.6	3.0	26.4	72.1	63.0	1.15
7	20.7	2.9	14.3	87.2	71.7	1.22
8	22.5	2.0	13.9	58.1	45.2	1.29
9	22.8	2.0	19.0	75.5	61.3	1.24
10	26.3	1.8	13.0	79.6	60.0	1.33
11	16.2	1.7	6.4	47.1	34.7	1.36
12	19.2	2.9	12.6	67.6	53.2	1.24
13	27.2	3.1	15.4	63.9	50.5	1.26
14	19.0	2.8	14.4	78.8	61.3	1.25
15	14.7	1.8	13.8	59.0	45.2	1.31
16	26.8	2.8	15.0	68.3	54.2	1.26
17	18.5	2.1	9.7	56.7	46.0	1.23
18	24.8	2.8	12.7	70.4	53.7	1.31
19	18.8	2.9	11.3	91.9	73.7	1.25
20	17.6	2.2	13.4	52.7	44.8	1.17
21	14.0	3.2	10.4	50.7	42.7	1.19
22	20.0	2.4	11.5	51.1	38.2	1.34
23	19.8	3.4	13.8	68.9	54.3	1.27
24	20.3	3.0	16.8	76.4	64.2	1.19
25	11.3	3.1	16.5	56.4	49.3	1.14
26	12.7	3.2	18.8	48.5	39.0	1.25
27	28.0	3.0	14.6	95.1	76.2	1.24
28	12.3	1.6	10.4	51.4	38.5	1.33
29	26.5	2.8	15.6	67.2	51.7	1.30
30	23.4	3.2	11.8	73.4	59.3	1.24
31	22.5	3.0	14.1	84.7	66.7	1.27
32	15.3	2.6	6.5	59.8	46.2	1.30
33	27.4	2.8	13.9	88.4	71.7	1.23
34	26.5	2.0	18.4	66.3	52.8	1.25
35	18.1	3.0	12.9	84.0	66.3	1.27
36	22.0	2.9	10.2	64.3	49.3	1.30
37	17.6	3.0	9.7	62.5	51.2	1.22
38	19.4	3.0	10.9	71.1	58.0	1.24
39	16.2	2.5	9.6	67.9	52.7	1.29
40	15.8	3.0	9.0	68.3	54.2	1.26
Mean	20.5	2.7	13.8	69.8	55.9	1.25
$LSD_{(.05)}$	4.0	1.4	4.7	9.8	8.1	0.14

Table A5 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
41	26.6	3.1	16.6	82.2	64.0	1.28
42	18.6	2.7	16.2	83.0	66.5	1.24
43	22.2	2.8	20.5	74.6	59.7	1.26
44	15.0	2.1	8.8	66.6	52.4	1.27
45	19.0	3.1	10.1	64.2	50.5	1.27
46	20.5	3.8	13.2	70.4	57.8	1.22
47	32.2	2.8	20.2	82.7	64.3	1.30
48	15.6	3.9	30.6	82.0	72.6	1.13
49	24.0	1.8	14.3	73.7	58.4	1.26
50	28.0	2.9	18.4	80.5	66.8	1.20
51	16.6	3.0	12.1	72.6	59.0	1.23
52	21.0	3.2	16.1	64.1	53.7	1.19
53	20.9	1.8	14.1	56.7	47.5	1.19
54	18.3	3.2	8.2	67.6	54.3	1.24
55	20.2	2.0	14.4	58.1	45.0	1.29
56	22.9	3.2	22.7	98.1	78.3	1.25
57	18.0	2.1	8.6	70.5	56.7	1.24
58	18.3	1.8	12.4	68.1	53.2	1.28
59	22.6	1.8	13.9	74.8	59.8	1.25
60	16.8	3.1	12.8	69.4	55.2	1.26
61	16.9	2.4	11.3	59.9	46.6	1.28
62	13.9	3.9	7.5	47.6	39.7	1.20
63	16.5	1.8	10.8	73.2	60.3	1.21
64	19.6	1.9	7.5	55.8	42.2	1.32
65	15.7	1.9	9.0	51.4	39.8	1.29
66	24.8	3.8	11.7	60.0	49.5	1.22
67	24.1	2.6	15.9	85.1	67.7	1.26
68	19.5	2.2	13.6	76.3	58.5	1.30
69	24.9	2.8	11.4	71.8	56.3	1.27
70	18.5	3.1	13.0	75.4	63.8	1.18
71	24.2	2.9	16.2	81.8	65.3	1.25
72	16.4	2.9	11.0	66.2	50.8	1.30
73	21.5	3.1	20.0	71.0	58.8	1.21
74	24.4	2.2	13.2	66.6	50.8	1.30
75	14.8	2.6	9.7	55.8	44.2	1.26
76	27.9	2.8	12.1	76.9	58.2	1.33
77	26.3	4.9	37.5	71.5	65.5	1.09
78	21.2	2.8	16.4	80.5	64.2	1.26
79	23.2	2.7	15.5	92.5	73.6	1.26
80	23.6	2.8	22.1	95.2	80.3	1.18
Mean	20.5	2.7	13.8	69.8	55.9	1.25
$LSD_{(.05)}$	4.0	1.4	4.7	9.8	8.1	0.14

Table A6. Mean values of 76 inbred entries for eight plant and grain traits at Ames in 1978

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[a] Absorbance	DATE Days
1	16.8	2.3	4.4	64.5	55.0	1.17	6.0	26.7
2	16.4	4.0	1.2	57.2	52.5	1.09	8.3	25.7
3	19.6	1.7	5.2	80.9	67.0	1.21	5.6	23.7
4	22.3	2.7	5.3	53.4	48.7	1.10	10.2	27.0
5	14.2	3.0	3.8	65.2	57.0	1.14	7.4	20.3
6	19.2	3.0	9.2	----	----	----	----	40.0
7	19.4	2.7	12.3	89.3	77.7	1.15	6.1	28.7
8	17.5	2.0	11.4	73.5	67.7	1.09	8.1	26.3
9	17.3	2.0	5.9	75.1	62.3	1.21	7.6	26.0
10	20.0	2.3	3.0	78.5	67.3	1.17	7.6	21.0
11	14.1	2.3	1.8	53.6	45.3	1.18	6.7	24.3
12	20.5	3.0	7.0	67.5	59.0	1.14	9.8	29.7
13	15.5	2.3	3.7	59.8	51.3	1.17	6.3	27.3
14	14.1	3.0	3.9	63.0	57.7	1.10	9.5	18.3
15	13.1	1.3	5.6	58.7	50.0	1.17	8.4	24.3
16	18.3	2.0	6.0	64.2	53.7	1.20	14.9	24.3
17	14.2	2.7	5.6	59.4	54.7	1.09	8.1	25.3
18	20.1	3.0	2.4	65.4	56.3	1.16	6.9	28.3
19	13.5	3.3	4.2	49.7	46.3	1.08	10.4	21.0
20	13.9	2.7	3.4	44.0	36.3	1.02	15.9	36.3
21	14.4	2.0	5.6	62.4	54.3	1.15	10.7	28.7
22	14.7	2.0	1.9	50.4	43.7	1.15	7.4	28.0
23	12.5	3.0	14.5	62.7	63.0	1.00	7.9	19.0
24	26.2	2.3	7.2	98.1	84.0	1.17	15.3	31.3
25	19.7	2.0	5.4	63.2	54.7	1.16	16.6	30.0
26	14.6	3.0	2.8	51.8	45.7	1.14	8.7	28.0
27	20.2	2.3	5.0	71.9	66.0	1.10	13.5	28.7
28	14.4	3.0	4.6	55.5	46.0	1.21	11.5	22.0
29	15.9	3.3	4.1	89.7	77.0	1.16	3.9	23.3
30	17.7	3.0	4.2	64.3	58.7	1.10	5.1	29.7
31	----	----	----	----	----	----	----	----
32	----	----	----	----	----	----	----	----
33	22.5	2.3	5.6	89.1	77.0	1.16	11.1	26.0
34	21.7	2.3	2.1	56.1	49.7	1.14	8.9	29.3
35	15.0	2.3	7.4	77.0	57.7	1.34	6.3	25.3
36	19.2	2.3	3.8	61.4	53.3	1.15	10.8	29.0
37	15.5	2.3	3.0	60.3	53.0	1.14	10.9	30.3
38	14.7	2.7	4.2	61.3	55.7	1.10	10.6	27.3
39	13.8	2.3	2.1	65.1	56.0	1.16	8.3	26.7
40	12.5	3.0	3.2	58.2	50.3	1.16	9.1	26.7
Mean	16.7	2.6	5.2	66.3	57.7	1.15	8.8	26.2
$LSD_{(.05)}$	2.0	0.8	3.6	6.3	7.6	0.10	3.0	3.4

[a]Values were multiplied by 10^2.

Table A6 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[a] Absorbance	DATE Days
41	15.2	3.0	3.6	65.6	56.0	1.17	7.1	22.7
42	15.1	2.0	3.6	73.6	66.3	1.11	6.5	28.0
43	20.0	3.0	3.8	58.8	52.8	1.12	7.9	29.7
44	13.5	2.7	2.9	63.1	56.0	1.13	4.2	20.3
45	13.4	3.0	1.3	50.0	44.0	1.15	3.9	25.3
46	15.2	3.3	4.3	68.7	58.0	1.19	6.5	23.0
47	19.2	3.0	4.9	73.8	65.3	1.13	7.6	27.7
48	12.6	3.7	14.5	72.9	68.3	1.07	8.8	25.3
49	16.3	4.0	4.3	63.8	53.7	1.19	6.7	22.7
50	21.3	3.0	4.8	78.2	66.3	1.18	6.6	27.3
51	12.9	3.3	4.6	62.0	54.7	1.14	8.0	23.7
52	23.2	3.0	6.2	74.6	65.3	1.14	17.7	26.7
53	18.3	1.7	6.6	60.2	52.7	1.15	11.5	25.3
54	19.2	3.0	4.4	63.1	54.3	1.16	9.7	21.0
55	15.5	2.3	3.1	55.5	47.3	1.17	8.9	29.3
56	17.6	3.3	10.4	87.7	79.3	1.10	11.0	25.0
57	16.6	1.0	2.9	74.1	61.0	1.22	6.3	24.0
58	13.5	2.0	1.9	54.5	44.3	1.23	5.2	24.7
59	16.5	1.7	7.4	74.8	66.7	1.12	14.9	25.3
60	13.6	2.7	4.0	68.1	58.3	1.17	5.5	28.0
61	17.8	1.0	1.6	65.9	54.7	1.20	5.3	28.7
62	12.6	4.3	2.8	47.0	38.7	1.23	10.1	26.7
63	15.6	1.3	8.3	71.3	59.0	1.21	9.5	28.0
64	15.9	2.3	1.5	52.7	44.3	1.19	5.1	25.7
65	13.6	2.3	5.3	56.1	47.7	1.18	8.9	22.0
66	16.5	1.0	4.2	48.8	44.0	1.11	7.4	31.3
67	----	----	----	----	----	----	----	----
68	----	----	----	----	----	----	----	----
69	19.3	3.0	1.5	61.8	52.0	1.22	7.5	24.0
70	16.1	3.0	9.0	77.4	72.7	1.07	11.6	30.3
71	20.5	2.3	3.8	88.1	72.7	1.22	8.0	26.0
72	13.3	2.3	2.6	62.8	53.7	1.17	7.3	21.3
73	13.9	1.7	10.8	64.1	59.0	1.09	5.7	27.0
74	21.2	1.3	2.9	64.3	53.3	1.21	8.9	27.3
75	12.6	4.3	2.8	47.0	38.7	1.23	10.1	26.7
76	19.7	2.3	3.6	74.8	62.0	1.21	8.9	29.0
77	14.9	4.7	13.0	53.6	48.0	1.12	10.8	30.0
78	16.3	2.0	5.9	84.0	72.0	1.17	6.2	28.7
79	20.0	3.0	6.4	91.1	78.7	1.16	13.8	25.3
80	19.6	2.3	17.5	92.7	81.5	1.14	9.6	26.7
Mean	16.7	2.6	5.2	66.3	57.7	1.15	8.8	26.2
$LSD_{(.05)}$	2.0	0.8	3.6	6.3	7.6	0.10	3.0	3.4

Table A7. Mean values of 76 inbred entries for three grain traits at Atomic Energy in 1978

Entry	MOIST %	RATE 1-5	BREAK %
1	12.7	1.7	4.5
2	13.3	4.3	6.8
3	13.7	1.3	6.5
4	12.3	2.7	9.7
5	11.2	2.7	8.5
6	13.6	3.0	14.4
7	17.3	2.3	16.7
8	13.2	2.5	4.0
9	15.0	1.0	10.4
10	16.2	1.7	7.0
11	12.9	2.7	5.3
12	14.2	2.7	8.5
13	17.1	2.3	6.4
14	11.8	1.5	4.9
15	12.4	1.0	5.9
16	12.9	2.0	5.1
17	12.4	3.0	9.1
18	13.5	3.0	4.6
19	11.8	3.0	7.4
20	14.2	2.0	15.6
21	14.6	3.0	10.1
22	13.4	2.0	10.1
23	9.8	3.0	17.1
24	20.0	2.0	13.1
25	13.5	1.7	6.0
26	10.0	3.0	6.5
27	14.4	2.0	7.2
28	12.7	2.3	5.5
29	13.6	2.3	8.9
30	14.1	2.3	14.9
31	----	---	----
32	----	---	----
33	19.8	2.0	8.6
34	16.7	1.5	9.8
35	12.0	2.0	7.0
36	14.3	2.3	5.4
37	11.6	3.0	11.4
38	10.6	3.7	7.1
39	11.8	1.5	4.9
40	12.2	3.0	6.2
Mean	13.7	2.4	9.8
$LSD_{(.05)}$	3.0	0.9	6.2

Table A7 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %
41	15.5	3.0	15.3
42	13.4	1.7	6.7
43	15.3	2.0	19.8
44	12.5	2.3	13.9
45	12.7	2.7	8.6
46	10.8	3.0	9.5
47	14.2	2.3	15.7
48	12.1	3.7	20.0
49	15.8	1.7	5.7
50	21.3	2.0	20.2
51	12.5	2.0	10.2
52	15.6	3.7	10.8
53	10.2	1.3	10.0
54	14.2	2.7	5.8
55	13.6	1.5	12.5
56	14.9	2.7	10.2
57	17.3	2.0	12.0
58	12.6	1.7	6.9
59	13.0	1.3	13.4
60	12.9	2.0	8.0
61	14.4	2.0	13.0
62	13.7	4.0	4.7
63	12.6	1.0	12.9
64	13.9	2.3	3.2
65	12.5	2.3	6.7
66	12.4	2.3	9.6
67	----	---	----
68	----	---	----
69	14.7	3.0	3.1
70	17.7	2.0	16.3
71	15.9	2.7	16.7
72	11.9	2.0	10.2
73	11.1	3.7	13.8
74	15.0	1.0	6.7
75	11.2	2.3	6.6
76	14.9	2.0	9.8
77	11.6	5.0	23.0
78	12.0	2.3	4.6
79	14.6	3.0	6.2
80	17.6	3.0	22.0
Mean	13.7	2.4	9.8
$LSD_{(.05)}$	3.0	0.9	6.2

Table A8. Mean values of 76 inbred entries for eight plant and grain traits data combined over two locations in 1978

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[a] Absorbance	DATE Days
1	14.7	2.0	4.5	64.5	55.0	1.17	6.0	26.7
2	16.7	4.2	10.3	57.2	52.5	1.09	8.3	25.7
3	16.7	1.5	5.8	80.9	67.0	1.21	5.6	23.7
4	17.3	2.7	7.5	53.4	48.0	1.10	10.2	27.0
5	12.7	2.8	6.1	65.2	57.0	1.14	7.4	20.3
6	15.8	3.0	12.4	----	----	----	----	40.0
7	18.3	2.5	14.5	89.3	77.7	1.15	6.1	28.7
8	16.4	2.2	9.6	73.5	67.7	1.09	8.1	26.3
9	16.1	1.5	8.1	75.1	62.3	1.21	7.6	26.0
10	18.1	2.0	5.0	78.5	67.3	1.17	7.6	21.0
11	13.5	2.5	3.5	53.6	45.3	1.18	6.7	24.3
12	18.0	2.8	7.6	67.5	59.0	1.14	9.8	29.7
13	16.3	2.3	4.8	59.8	51.3	1.17	6.3	27.3
14	12.7	3.2	4.7	63.0	57.7	1.10	9.5	18.3
15	12.8	1.2	5.8	58.7	50.0	1.17	8.4	24.3
16	15.6	2.0	5.5	64.2	53.7	1.20	14.9	24.3
17	13.3	2.8	7.3	59.4	54.7	1.09	8.1	25.3
18	16.8	3.0	3.5	65.4	56.3	1.16	6.9	28.3
19	16.7	3.2	5.8	49.7	46.3	1.08	10.4	21.0
20	14.0	2.4	9.5	36.3	44.0	1.02	15.9	36.3
21	14.5	2.5	7.9	62.4	54.3	1.15	10.7	28.7
22	14.0	2.0	6.0	50.4	43.7	1.15	7.4	28.0
23	11.1	3.0	15.8	62.7	63.0	1.00	7.9	19.0
24	23.1	2.2	10.1	98.1	84.0	1.17	15.3	31.3
25	16.6	1.8	5.6	63.2	54.7	1.16	16.6	30.0
26	12.3	3.0	4.6	51.8	45.7	1.14	8.7	28.0
27	17.3	2.2	6.1	71.9	66.0	1.10	13.5	28.7
28	13.6	2.7	5.0	55.5	46.0	1.21	11.5	22.0
29	14.7	2.8	6.5	89.7	77.0	1.16	3.9	23.3
30	16.3	2.7	8.5	64.3	58.7	1.10	5.1	29.7
31	----	---	----	----	----	----	----	----
32	----	---	----	----	----	----	----	----
33	21.2	2.2	7.1	89.1	77.0	1.16	11.1	26.0
34	20.5	2.0	4.0	56.1	49.7	1.14	8.9	29.3
35	13.5	2.2	7.2	77.0	57.7	1.34	6.3	25.3
36	16.8	2.3	4.6	61.4	53.3	1.15	10.8	29.0
37	13.5	2.7	7.2	60.3	53.0	1.14	10.9	30.3
38	12.6	3.2	5.7	61.3	55.7	1.10	10.6	27.3
39	12.8	2.0	3.5	65.1	56.0	1.16	8.3	26.7
40	12.4	3.0	4.7	58.2	50.3	1.16	9.1	26.7
Mean	15.2	2.5	7.4	66.3	57.7	1.15	8.8	26.2
$LSD_{(.05)}$	5.1	0.9	5.4	6.2	7.5	0.10	3.0	3.4

[a]Values were multiplied by 10^2.

Table A8 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[a] Absorbance	DATE Days
41	15.3	3.0	9.5	65.6	56.0	1.17	7.1	22.7
42	14.4	1.8	4.8	73.6	66.3	1.11	6.5	28.0
43	17.6	2.5	11.8	58.8	52.8	1.12	7.9	29.7
44	13.0	2.5	8.4	63.1	56.0	1.13	4.2	20.3
45	13.0	2.8	4.9	50.0	44.0	1.15	3.9	25.3
46	13.0	3.2	6.9	68.7	58.0	1.19	6.5	23.0
47	16.7	2.7	10.3	73.8	65.3	1.13	7.6	27.7
48	12.4	3.7	16.7	72.9	68.3	1.07	8.8	25.3
49	16.0	2.8	5.0	63.8	53.7	1.19	6.7	22.7
50	21.3	2.6	12.5	78.2	66.3	1.18	6.6	27.3
51	12.7	2.8	7.4	62.0	54.7	1.14	8.0	23.7
52	19.4	3.3	8.5	74.6	65.3	1.14	17.7	26.7
53	14.2	1.5	8.3	60.2	52.7	1.15	11.5	25.3
54	16.7	2.8	5.1	63.1	54.3	1.16	9.7	21.0
55	14.5	2.0	7.8	55.5	47.3	1.17	8.9	29.3
56	16.2	3.0	10.3	87.7	79.3	1.10	11.0	25.0
57	16.9	1.5	7.4	74.1	61.0	1.22	6.3	24.0
58	13.0	1.8	4.4	54.5	44.3	1.23	5.2	24.7
59	14.8	1.5	10.4	74.8	66.7	1.26	14.9	25.3
60	13.2	2.3	6.0	68.1	58.3	1.17	5.5	28.0
61	16.1	1.6	7.3	65.9	54.7	1.20	5.3	28.7
62	13.1	4.2	3.8	47.0	38.7	1.23	10.1	26.7
63	14.1	1.2	10.6	71.3	59.0	1.21	9.5	28.0
64	14.9	2.3	2.3	52.7	44.3	1.19	5.1	25.7
65	13.1	2.3	6.0	56.1	47.7	1.18	8.9	22.0
66	14.4	2.0	6.4	48.8	44.0	1.11	7.4	31.3
67	----	----	----	----	----	----	----	----
68	----	----	----	----	----	----	----	----
69	17.0	3.0	2.3	61.8	52.0	1.22	7.5	24.0
70	16.9	2.5	12.6	77.4	72.7	1.07	11.6	30.3
71	18.2	2.5	11.5	72.7	88.1	1.22	8.0	26.0
72	12.6	2.2	6.4	62.8	53.7	1.17	7.3	21.3
73	12.5	2.7	11.6	64.1	59.0	1.09	5.7	27.0
74	18.1	1.2	4.8	64.3	53.3	1.21	8.9	27.3
75	12.0	2.7	4.7	47.0	38.7	1.23	10.1	26.7
76	17.3	2.2	6.7	74.8	62.0	1.21	8.9	29.0
77	13.2	4.8	18.0	53.6	48.0	1.12	10.8	30.0
78	14.2	2.2	5.4	84.0	72.0	1.17	6.2	28.7
79	17.8	3.0	6.3	91.1	78.7	1.16	13.8	25.3
80	18.6	2.7	19.7	92.7	81.5	1.14	9.6	26.7
Mean	15.2	2.5	7.4	66.3	57.7	1.15	8.8	26.2
$LSD_{(.05)}$	5.1	0.9	5.4	6.2	7.5	0.10	3.0	3.4

Table A9. Mean values of 80 inbred entries for eight plant and grain traits data combined over locations and years

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[a] Absorbance	DATE Days
1	16.0	2.4	6.1	69.7	55.3	1.26	6.0	26.7
2	19.2	4.3	8.9	54.6	47.9	1.14	8.3	25.7
3	19.8	1.8	8.6	86.4	68.7	1.26	5.6	23.7
4	18.9	2.7	8.9	50.5	42.2	1.21	10.2	27.0
5	14.1	3.0	7.9	67.1	55.3	1.22	7.4	20.3
6	17.0	3.0	19.1	72.2	63.0	1.15	----	40.0
7	19.6	2.7	14.4	87.9	73.7	1.19	6.1	28.7
8	18.9	2.1	10.8	63.2	52.7	1.22	8.1	26.3
9	19.5	1.8	13.6	75.5	61.6	1.23	7.6	26.0
10	22.2	1.9	9.0	79.2	62.4	1.28	7.6	21.0
11	14.8	2.1	5.0	49.3	38.2	1.30	6.7	24.3
12	18.3	2.9	9.8	66.3	54.4	1.22	9.8	29.7
13	21.7	2.7	10.2	62.5	50.8	1.23	6.3	27.3
14	15.8	3.0	9.5	75.2	60.1	1.20	9.5	18.3
15	13.7	1.5	9.8	58.9	46.8	1.26	8.4	24.3
16	21.2	2.4	10.2	66.9	54.0	1.24	14.9	24.3
17	15.9	2.4	8.6	57.6	48.9	1.18	8.1	25.3
18	20.8	2.9	8.1	68.7	54.5	1.26	6.9	28.3
19	15.7	3.0	8.6	77.8	64.6	1.19	10.4	21.0
20	15.8	2.3	11.4	49.9	44.6	1.12	15.9	36.3
21	14.2	2.8	9.2	54.6	46.5	1.18	10.7	28.7
22	17.0	2.2	8.7	50.8	40.2	1.27	7.4	28.0
23	15.5	3.2	14.8	66.8	57.2	1.18	7.9	19.0
24	21.7	2.6	13.5	83.6	70.8	1.18	15.3	31.3
25	14.0	2.5	11.1	58.7	51.1	1.15	16.6	30.0
26	12.5	3.1	6.8	49.6	41.2	1.21	8.7	28.0
27	22.6	2.6	10.4	87.4	72.8	1.20	13.5	28.7
28	12.9	2.1	7.7	52.8	41.0	1.29	11.5	22.0
29	20.6	2.8	11.0	74.7	60.1	1.26	3.9	23.3
30	19.6	2.9	10.7	70.3	59.1	1.20	5.1	29.7
31	22.4	3.0	15.0	83.8	66.5	1.26	----	----
32	15.8	2.6	6.4	59.8	46.2	1.30	----	----
33	24.3	2.5	10.5	88.6	73.5	1.21	11.1	26.0
34	23.2	2.0	12.2	63.4	52.0	1.22	8.9	29.3
35	15.8	2.6	10.0	81.7	63.5	1.29	6.3	25.3
36	19.4	2.6	7.4	63.4	50.6	1.25	10.8	29.0
37	15.6	2.8	8.4	61.6	51.8	1.20	10.9	30.3
38	16.0	3.1	8.6	67.6	57.3	1.18	10.6	27.3
39	14.5	2.2	6.6	67.0	53.8	1.25	8.3	26.7
40	14.1	3.0	6.9	64.9	52.9	1.22	9.1	26.7
Mean	17.9	2.6	10.7	68.7	56.5	1.22	8.8	26.2
$LSD_{(.05)}$	3.5	0.6	4.1	10.4	8.7	0.06	3.0	3.4

[a]Values were multiplied by 10^2.

Table A9 (Continued)

Entry	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[a] Absorbance	DATE Days
41	21.0	3.0	12.7	75.9	60.9	1.24	7.1	22.7
42	16.4	2.2	10.7	79.8	66.4	1.20	6.5	28.0
43	19.9	2.7	16.2	69.3	57.3	1.21	7.9	29.7
44	15.1	2.3	9.3	66.3	54.1	1.23	4.2	20.3
45	16.0	3.0	7.6	59.4	48.3	1.23	3.9	25.3
46	16.7	3.4	10.1	69.9	57.9	1.21	6.5	23.0
47	24.4	2.8	15.2	79.8	64.6	1.24	7.6	27.7
48	14.0	3.8	23.9	79.1	71.5	1.11	8.8	25.3
49	20.0	2.3	9.6	70.0	56.5	1.24	6.7	22.7
50	24.6	2.7	15.4	79.7	66.7	1.19	6.6	27.3
51	14.9	2.8	9.8	68.7	57.4	1.19	8.0	23.7
52	20.2	3.2	12.3	67.6	57.5	1.18	17.7	26.7
53	17.6	1.6	11.2	57.9	49.2	1.18	11.5	25.3
54	17.5	3.0	6.7	66.1	54.3	1.22	9.7	21.0
55	17.4	2.0	11.1	57.2	45.8	1.25	8.9	29.3
56	19.6	3.1	16.5	94.6	78.7	1.20	11.0	25.0
57	17.5	1.8	8.0	71.7	58.1	1.24	6.3	24.0
58	15.7	1.8	8.4	63.6	50.2	1.26	5.2	24.7
59	18.7	1.7	12.2	74.8	62.1	1.21	14.9	25.3
60	15.0	2.7	9.3	69.0	56.2	1.23	5.5	28.0
61	16.5	1.9	9.3	59.8	47.8	1.25	5.3	28.7
62	13.5	4.0	5.6	47.4	39.3	1.21	10.1	26.7
63	15.3	1.5	10.8	72.6	59.9	1.21	9.5	28.0
64	17.2	2.1	4.9	54.7	42.9	1.28	5.1	25.7
65	14.4	2.1	7.5	52.9	42.5	1.25	8.9	22.0
66	19.6	2.8	9.3	56.2	47.7	1.18	7.4	31.3
67	24.1	2.6	15.2	85.1	67.7	1.26	----	----
68	19.5	2.2	13.6	76.3	58.5	1.30	----	----
69	21.0	2.9	6.9	68.5	54.9	1.24	7.5	24.0
70	17.7	2.8	12.8	76.0	66.8	1.14	11.6	30.3
71	21.2	2.7	13.2	83.9	67.8	1.24	8.0	26.0
72	14.5	2.5	8.7	65.1	51.8	1.26	7.3	21.3
73	17.0	2.9	16.2	68.7	58.9	1.17	5.7	27.0
74	21.3	1.7	9.0	65.8	51.7	1.28	8.9	27.3
75	13.4	2.6	7.2	57.5	46.8	1.23	8.5	22.7
76	22.6	2.4	9.4	76.2	59.5	1.29	8.9	29.0
77	19.8	4.9	27.7	65.6	59.7	1.10	10.8	30.0
78	17.6	2.5	10.8	81.7	66.8	1.23	6.2	28.7
79	20.2	2.8	10.9	90.8	74.4	1.22	13.8	25.3
80	21.1	2.8	20.9	94.4	80.7	1.17	9.6	26.7
Mean	17.9	2.6	10.7	68.7	56.5	1.22	8.8	26.2
$LSD_{(.05)}$	3.5	0.6	4.1	10.4	8.7	0.06	3.0	3.4

Table A10. Analyses of variance for six grain traits for 80 inbred entries at Ames in 1976

		Mean squares					
Source	d.f.	MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]
Replications	2	32.22	63.18	46.33	221.38	222.55	65.41
Genotypes	79	76.73**	135.46**	73.50**	452.62**	301.54**	78.74**
Error[c]	158	15.25	12.60	6.33	42.64	31.73	26.43

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A16 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A11. Analyses of variance for six grain traits for 80 inbred entries at Ankeny in 1976

		Mean squares					
Source	d.f.	MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]
Replications	2	3.16	5.17	1.49	99.58	67.47	12.84
Genotypes	79	47.31**	107.84**	99.42**	496.78**	363.57**	99.99**
Error[c]	158	3.85	10.90	6.87	28.28	25.89	31.54

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A16 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A12. Analyses of variance for six grain traits for 80 inbred entries data combined over two locations in 1976

Source	d.f.	Mean squares					
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]
Locations (L)	1	3718.22	82.23	4076.53	11265.92	3401.51	4283.12
Replications/L	4	17.69	34.18	23.91	160.48	145.01	39.12
Genotypes (G)	79	112.30**	228.41**	151.29**	877.02**	616.10**	146.37**
G x L	79	11.73	14.90	16.62**	72.38**	49.02**	32.28
Error[c]	316	9.66	11.74	6.60	35.22	28.71	29.05

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A16 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A13. Analyses of variance for eight plant and grain traits for 76 inbred entries at Ames in 1978

Source	d.f.	Mean squares							
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Replications	2	18.77	13.64	2.11	45.60	121.14	109.01	15.37	21.55
Genotypes	75	28.38**	13.88**	32.06**	401.09**	298.40**	77.58**	26.37**	35.96**
Error[c]	150	1.55	2.61	4.83	14.90	21.54	41.08	3.40	4.30

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A16 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A14. Analyses of variance for three grain traits for 76 inbred entries at Atomic Energy in 1978

Source	d.f.	Mean squares MOIST	RATE[a]	BREAK
Replications	2	1.77	14.11	3.96
Genotypes	75	14.98**	177.12**	60.41**
Error[b]	150	3.34	29.80	14.58

[a]Mean squares were multiplied by 10^2.

[b]See Table A16 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A15. Analyses of variance for eight plant and grain traits for 76 inbred entries data combined over two locations in 1978

Source	d.f.	Mean squares							
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Locations (L)	1(0)[c]	1025.44	265.14	2284.85	----	----	----	----	----
Replications/L	4(2)	10.27	75.26	3.03	45.60	121.14	109.01	15.37	21.55
Genotypes (G)	75(75)	35.70**	257.93**	70.93**	401.09**	298.40**	77.58**	26.37**	35.96**
G x L	75(0)	7.66**	58.04**	21.54**	----	----	----	----	----
Error[d]	300(150)	2.43	28.00	9.51	14.90	21.54	41.08	3.40	4.30

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]Degrees of freedom for WT, VOL, DEN, GRN, DATE.

[d]See Table A16 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A16. Error degrees of freedom for inbred analyses of variance

Analysis	Trait							
	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
1976 Ames	157	148	150	145	145	145	---	---
1976 Ankeny	152	155	154	155	155	155	---	---
1976 Combined	309	303	304	300	300	300	---	---
1978 Ames	148	140	145	140	140	140	142	149
1978 Atomic Energy	141	140	134	---	---	---	---	---
1978 Combined	289	280	279	---	---	---	---	---
Combined	598	583	583	440	440	440	142	149

Table A17. Correlation coefficients between six grain traits for 80 inbred entries, at Ames 1976 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST		0.15	0.35**	0.46**	0.43**	0.14
RATE	0.16		0.40**	0.21	0.32**	-0.50**
BREAK	0.35	0.44		0.36**	0.45**	-0.33**
WT	0.49	0.22	0.37		0.98**	0.14
VOL	0.46	0.34	0.47	0.98		-0.07
DEN	0.20	-0.62	-0.42	0.16	-0.02	

**Significant at the 0.01 level of probability.

Table A18. Correlation coefficients between six grain traits for 80 inbred entries, at Ankeny 1976 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST		0.02	0.38**	0.49**	0.44**	0.02
RATE	0.01		0.28**	0.06	0.17	-0.51**
BREAK	0.38	0.32		0.45**	0.58**	-0.66**
WT	0.52	0.07	0.48		0.97**	-0.25*
VOL	0.47	0.20	0.62	0.98		-0.47**
DEN	0.06	-0.67	-0.81	-0.30	-0.48	

**Significant at the 0.01 level of probability.

Table A19. Correlation coefficients between six grain traits for 80 inbred entries, data combined over locations in 1976 (simple _r_ values above and genotypic _r_ values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST		0.11	0.38**	0.50**	0.46**	0.08
RATE	0.13		0.38**	0.14	0.25*	-0.55**
BREAK	0.41	0.44		0.44**	0.55**	-0.54**
WT	0.52	0.15	0.47		0.98**	-0.10
VOL	0.48	0.26	0.58	0.98		-0.30
DEN	0.08	-0.63	-0.58	-0.13	-0.32	

**Significant at the 0.01 level of probability.

Table A20. Correlation coefficients between eight plant and grain traits for 76 inbred entries, at Ames 1978 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.15	0.07	0.52**	0.48**	0.12	0.34**	0.33**
RATE	-0.25		0.12	-0.11	-0.05	-0.25*	0.03	-0.12
BREAK	0.06	0.13		0.42**	0.53**	-0.35**	0.22	0.08
WT	0.53	-0.14	0.44		0.97**	0.15	0.08	-0.01
VOL	0.50	-0.06	0.55	0.98		-0.10	0.14	0.01
DEN	0.17	-0.44	-0.52	0.23	0.05		-0.25*	-0.13
GRN	0.35	0.03	0.24	0.08	0.12	-0.40		0.30*
DATE	0.35	-0.12	0.09	-0.01	0.02	-0.24	0.30	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A21. Correlation coefficients between three grain traits for 76 inbred entries, at Atomic Energy 1978 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK
MOIST		-0.20	0.32**
RATE	-0.27		0.14
BREAK	0.33	0.16	

**Significant at the 0.01 level of probability.

Table A22. Correlation coefficients between eight plant and grain traits for 76 inbred entires, data combined over locations in 1978 (simple r values and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.19	0.17	0.52**	0.48**	0.12	0.34**	0.33**
RATE	-0.21		0.18	-0.11	-0.05	-0.25*	0.03	-0.12
BREAK	0.15	0.26		0.42**	0.53**	-0.35**	0.22	0.08
WT	0.53	-0.14	0.44		0.97**	0.15	0.08	-0.01
VOL	0.50	-0.06	0.55	0.98		-0.10	0.14	0.01
DEN	0.17	-0.44	-0.52	0.23	0.05		-0.25	-0.13
GRN	0.35	0.03	0.24	0.08	0.12	-0.40		0.30*
DATE	0.35	-0.12	0.09	-0.01	0.02	-0.24	0.30	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A23. Plot-mean simple correlation coefficients for 80 inbred entries between eight plant and grain traits at Ames 1979

	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST	-0.03	0.19**	0.46**	0.46**	-0.06	0.26**	0.05
RATE		0.04	-0.13*	-0.08	-0.21**	0.01	0.13*
BREAK			0.27**	0.32**	-0.16*	0.12	0.07
WT				0.96**	0.04	0.06	-0.14*
VOL					-0.22**	0.09	-0.10
DEN						-0.10	-0.11
GRN							0.13*

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A24. Mean values of 40 hybrid entries for six grain traits at Ames in 1976

Entry[a]	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
81	17.0	4.2	10.4	73.3	60.7	1.21
82	16.4	4.2	14.5	61.7	52.3	1.18
83	11.3	4.3	4.8	56.8	45.7	1.25
84	13.4	4.2	9.4	69.4	57.3	1.21
85	14.5	4.5	15.7	78.3	65.0	1.21
86	14.8	4.5	8.5	75.6	61.7	1.22
87	15.9	3.0	7.6	60.6	47.0	1.29
88	15.5	3.2	4.2	70.3	56.3	1.25
89	13.4	3.0	12.4	80.4	63.3	1.27
90	18.2	4.0	10.0	83.9	70.7	1.19
91	15.0	5.0	9.1	55.8	46.7	1.20
92	13.2	4.5	11.3	60.7	50.3	1.21
93	16.8	4.5	11.9	61.6	48.7	1.27
94	17.6	4.2	10.6	76.9	61.0	1.26
95	14.7	4.5	17.0	81.7	68.3	1.20
96	21.8	3.7	8.7	71.0	56.0	1.27
97	21.5	3.7	10.2	93.6	76.0	1.23
98	11.9	2.2	5.4	67.8	53.3	1.27
99	20.3	4.0	9.0	74.6	58.7	1.27
100	14.7	3.7	5.0	62.5	51.0	1.22
101	12.1	4.0	8.2	60.0	48.7	1.23
102	18.9	3.8	13.8	104.9	86.7	1.21
103	12.5	4.2	8.0	57.8	48.0	1.20
104	16.5	3.7	7.2	77.4	61.7	1.26
105	14.7	4.2	8.2	75.1	57.7	1.31
106	18.0	3.5	14.4	89.9	72.0	1.25
107	15.9	4.5	7.9	65.0	53.3	1.22
108	18.9	4.0	10.4	76.7	59.7	1.28
109	16.3	3.7	10.3	74.3	60.0	1.24
110	17.8	4.0	6.2	69.5	54.7	1.27
111	14.8	4.0	9.7	68.2	54.7	1.25
112	20.7	3.3	8.2	79.3	64.0	1.24
113	16.5	3.8	8.4	91.3	73.0	1.25
114	17.1	4.2	8.9	79.4	63.0	1.26
115	16.6	3.0	6.9	63.6	50.3	1.26
116	15.5	2.7	5.3	57.7	48.3	1.34
117	14.1	4.2	9.6	80.0	64.7	1.24
118	16.2	3.5	15.3	53.7	45.7	1.17
119	19.4	4.2	11.7	73.2	56.3	1.30
120	23.3	3.0	4.4	75.3	59.0	1.28
Mean	16.4	3.8	9.5	72.2	58.2	1.24
$LSD_{(.05)}$	4.9	0.5	2.8	8.8	7.4	0.07

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

Table A25. Mean values of 40 hybrid entries for six grain traits at Ankeny in 1976

Entry[a]	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
81	22.4	3.5	16.4	83.4	68.0	1.23
82	27.7	4.2	21.0	72.2	62.7	1.15
83	18.2	4.2	8.1	65.8	52.7	1.25
84	19.8	3.7	13.1	69.2	58.0	1.19
85	21.6	4.5	17.7	88.4	72.7	1.22
86	22.7	4.3	16.1	84.7	70.3	1.20
87	21.3	3.0	10.3	71.3	54.3	1.31
88	22.8	3.0	9.8	77.6	57.0	1.38
89	20.6	3.0	13.5	94.5	73.0	1.29
90	23.8	3.8	16.4	93.3	78.0	1.20
91	19.1	4.7	8.7	55.2	45.3	1.22
92	20.0	4.3	18.1	67.2	57.0	1.18
93	21.4	4.3	20.3	69.5	53.0	1.32
94	21.9	3.5	13.3	80.3	65.7	1.22
95	21.4	4.0	19.4	84.3	70.7	1.19
96	24.5	3.7	14.9	76.9	61.7	1.25
97	25.8	4.0	17.2	103.5	84.3	1.23
98	19.0	2.2	14.4	72.0	55.7	1.30
99	25.2	3.5	13.7	76.8	57.7	1.34
100	22.0	3.5	10.5	70.5	56.7	1.24
101	20.8	3.5	15.9	76.7	61.3	1.25
102	25.1	3.7	25.0	115.1	96.7	1.19
103	23.2	4.2	19.4	83.6	68.3	1.22
104	19.3	3.3	13.8	77.4	61.7	1.25
105	20.2	3.7	12.1	82.4	63.7	1.31
106	21.0	3.7	18.1	81.4	66.3	1.23
107	22.1	3.7	11.4	64.7	53.3	1.21
108	20.5	3.2	15.8	78.5	64.3	1.22
109	24.8	3.8	12.3	77.1	63.0	1.22
110	23.9	4.0	10.9	79.5	66.0	1.21
111	23.9	4.0	16.1	75.8	61.3	1.24
112	25.0	3.0	12.5	90.3	71.7	1.26
113	23.9	3.0	15.7	95.6	75.3	1.27
114	23.6	3.8	12.4	90.3	70.0	1.29
115	22.1	2.8	12.4	70.9	55.0	1.29
116	19.8	3.0	8.8	65.0	51.3	1.27
117	23.0	3.6	12.9	80.2	62.7	1.28
118	21.4	3.0	19.4	63.5	54.0	1.18
119	24.7	4.0	15.8	78.9	65.0	1.21
120	21.8	2.8	11.5	78.8	59.3	1.34
Mean	22.3	3.6	14.6	79.1	63.6	1.25
$LSD_{(.05)}$	3.5	0.6	6.1	8.8	7.8	0.11

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

Table A26. Mean values of 40 hybrid entries for six grain traits data combined over two locations in 1976

Entry[a]	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml
81	19.0	4.1	9.6	64.9	53.3	1.22
82	23.2	3.7	11.8	74.0	58.8	1.26
83	19.7	3.6	13.1	77.6	62.0	1.25
84	20.2	3.4	12.1	93.4	74.2	1.26
85	22.9	3.2	10.4	84.8	67.8	1.25
86	17.6	2.8	7.0	61.4	47.3	1.30
87	19.1	4.4	16.1	65.6	50.8	1.29
88	18.6	3.0	9.0	66.0	50.7	1.30
89	19.3	2.9	9.6	67.3	52.7	1.28
90	16.6	3.9	11.2	69.3	57.7	1.20
91	19.4	4.0	12.9	72.0	58.0	1.24
92	21.0	3.9	13.2	88.6	74.3	1.19
93	18.8	3.2	17.4	58.6	49.9	1.17
94	20.9	4.0	8.6	74.5	60.3	1.24
95	18.7	4.4	12.3	80.2	66.0	1.21
96	18.4	3.6	7.8	66.5	53.8	1.24
97	22.8	3.8	11.3	75.7	58.2	1.31
98	20.3	4.0	10.6	84.8	66.5	1.28
99	17.4	3.9	10.2	78.8	60.7	1.31
100	16.4	3.8	12.0	68.3	55.0	1.24
101	23.6	3.8	13.7	98.5	80.2	1.23
102	16.6	4.4	14.7	63.9	53.7	1.19
103	18.5	3.9	11.2	80.1	63.7	1.26
104	18.0	4.2	18.2	83.0	69.5	1.19
105	17.8	4.2	13.7	70.7	58.2	1.21
106	19.5	3.6	16.3	85.7	69.2	1.24
107	19.7	3.8	13.4	78.3	64.3	1.22
108	22.1	4.2	17.8	67.0	57.5	1.16
109	22.6	2.9	7.9	77.1	59.2	1.31
110	17.0	3.0	13.0	87.4	68.2	1.28
111	14.7	4.2	6.4	61.3	49.2	1.25
112	15.4	2.2	9.9	69.9	54.5	1.28
113	17.0	4.8	8.9	55.5	46.0	1.21
114	17.9	3.5	10.5	77.4	61.7	1.26
115	19.8	3.8	11.9	78.6	63.3	1.24
116	22.0	4.1	13.8	76.0	60.7	1.26
117	20.6	3.7	11.3	75.7	61.5	1.23
118	19.2	3.1	7.0	73.9	56.7	1.32
119	18.1	4.5	16.7	83.4	68.8	1.21
120	22.0	3.8	19.4	110.0	91.7	1.20
Mean	19.3	3.7	12.0	75.6	60.9	1.24
$LSD_{(.05)}$	3.4	0.4	3.6	8.1	9.6	0.02

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

Table A27. Mean values of 38 hybrid entries for eight plant and grain traits at Ames in 1978

Entry[a]	MOIST %	RATE 1-3	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
81	15.8	2.7	1.8	72.3	64.0	1.13	4.8	21.0
82	20.5	2.0	3.6	79.5	70.0	1.14	9.5	20.0
83	16.0	1.7	5.9	79.5	68.0	1.17	3.6	21.0
84	17.4	1.7	5.5	95.7	82.0	1.14	4.5	22.7
85	18.5	1.0	5.5	85.0	78.0	1.15	6.4	22.0
86	15.8	1.3	2.8	75.2	65.3	1.16	5.2	19.3
87	17.3	2.0	6.3	68.7	60.7	1.13	9.3	22.0
88	16.0	2.3	4.3	73.2	64.3	1.14	9.5	22.7
89	16.9	1.0	2.4	71.7	58.3	1.23	5.5	22.0
90	14.5	1.0	3.2	61.5	55.0	1.12	7.8	22.0
91	15.5	1.3	5.0	73.6	63.3	1.16	7.0	21.7
92	18.1	2.0	4.4	91.7	83.3	1.10	5.1	22.0
93	16.6	1.3	4.8	69.1	58.7	1.18	13.3	22.3
94	19.4	2.0	4.4	77.2	65.7	1.18	7.7	22.0
95	15.6	2.3	4.9	78.9	69.0	1.14	4.9	24.0
96	----	----	----	----	----	----	----	----
97	22.5	1.0	3.7	82.4	72.3	1.14	9.6	22.0
98	17.6	1.7	3.0	93.1	80.0	1.17	5.0	21.3
99	14.4	1.7	2.6	77.5	67.3	1.15	7.5	22.3
100	14.2	1.3	3.0	76.2	64.3	1.19	5.7	21.0
101	20.7	1.3	4.6	96.7	85.7	1.13	7.4	23.7
102	14.3	3.0	4.0	65.3	55.3	1.18	5.9	20.3
103	14.9	1.7	4.0	83.4	74.0	1.13	5.6	21.7
104	17.3	2.7	11.5	88.9	79.7	1.12	6.6	20.7
105	17.6	2.3	6.0	77.0	66.0	1.17	8.2	24.7
106	18.0	1.7	6.0	79.3	69.0	1.15	11.1	21.7
107	18.1	2.0	7.6	73.5	64.0	1.15	6.1	19.7
108	18.4	2.3	5.4	68.0	58.3	1.17	4.6	23.0
109	16.6	1.3	3.5	78.6	68.0	1.16	6.0	21.3
110	14.8	1.0	6.3	87.6	70.7	1.24	6.2	20.3
111	14.2	2.5	3.2	72.1	64.0	1.13	6.4	22.7
112	15.0	1.0	3.3	78.0	62.7	1.24	3.8	21.7
113	16.4	2.7	5.2	66.3	59.3	1.12	7.1	22.7
114	----	----	----	----	----	----	----	----
115	16.5	1.3	5.2	84.5	78.0	1.08	7.0	21.3
116	17.9	2.0	4.4	77.4	61.7	1.25	8.3	20.0
117	17.2	2.0	4.0	81.0	73.0	1.11	5.4	21.0
118	17.3	1.3	2.0	83.5	65.7	1.28	6.5	22.0
119	14.4	2.7	7.5	85.4	75.3	1.13	5.2	22.0
120	21.3	1.3	11.7	108.3	99.0	1.09	14.1	19.7
Mean	16.9	1.8	4.8	79.4	68.7	1.16	6.9	21.7
$LSD_{(.05)}$	1.5	0.9	2.9	11.1	9.2	0.11	3.0	2.1

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A28. Mean values of 38 hybrid entries for seven grain traits at Atomic Energy 1978

Entry[a]	MOIST %	RATE 1-3	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance
81	13.2	3.0	3.5	56.9	52.3	1.09	12.5
82	18.0	1.3	6.7	69.4	58.0	1.20	7.9
83	13.6	1.0	8.0	64.9	58.7	1.11	9.2
84	15.1	1.0	3.9	78.8	70.7	1.12	9.1
85	13.5	1.0	3.4	65.7	60.0	1.10	9.6
86	12.9	1.0	2.4	59.6	51.7	1.15	6.4
87	12.3	3.0	5.9	64.0	57.3	1.12	9.0
88	14.6	1.0	5.8	63.7	55.3	1.15	8.9
89	13.8	1.0	8.3	58.3	51.0	1.14	6.4
90	11.7	1.7	2.7	48.4	42.7	1.15	11.9
91	15.9	1.0	4.2	72.6	58.3	1.26	9.5
92	14.2	2.0	4.9	68.0	62.7	1.09	9.2
93	13.1	2.0	6.3	59.0	53.7	1.10	13.0
94	17.5	2.0	3.7	65.5	56.3	1.16	8.9
95	15.2	2.7	3.0	73.4	65.7	1.12	6.5
96	----	----	----	----	----	----	----
97	18.9	1.3	2.9	67.8	59.0	1.15	9.1
98	12.9	1.7	3.2	70.0	59.3	1.18	6.6
99	12.0	2.0	4.1	59.1	53.0	1.12	14.3
100	13.8	2.0	3.5	67.4	59.0	1.14	10.6
101	16.8	1.3	7.8	81.6	73.7	1.11	10.5
102	12.7	2.7	2.2	57.9	53.0	1.09	10.9
103	13.0	1.7	4.1	63.2	55.5	1.14	7.6
104	15.4	2.7	4.9	59.1	54.7	1.08	11.2
105	17.5	2.0	4.6	68.0	61.7	1.10	9.5
106	11.9	2.0	4.3	57.8	51.7	1.12	9.9
107	13.7	1.7	7.7	69.9	62.3	1.12	8.9
108	18.6	1.7	2.4	63.1	57.7	1.09	8.9
109	12.8	1.0	1.3	62.1	52.0	1.20	7.0
110	12.5	1.0	5.4	77.9	69.3	1.12	8.6
111	13.8	2.0	8.8	65.7	61.3	1.07	6.7
112	13.2	1.0	2.2	58.9	52.7	1.12	7.0
113	13.0	3.0	2.3	51.1	46.3	1.10	11.0
114	----	----	----	----	----	----	----
115	13.8	1.3	8.3	68.4	58.3	1.18	11.3
116	14.1	2.0	4.1	66.9	58.3	1.15	10.7
117	17.6	2.0	3.2	71.9	65.0	1.11	7.5
118	15.9	1.0	3.2	70.0	56.7	1.24	8.2
119	12.6	2.7	5.2	68.6	62.7	1.10	8.8
120	14.4	1.0	10.4	80.7	74.0	1.09	11.4
Mean	14.4	1.7	4.7	65.7	58.2	1.13	9.3
$LSD_{(.05)}$	1.9	0.7	4.4	7.5	7.6	0.09	3.5

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A29. Mean values of 38 hybrid entries for eight plant and grain traits data combined over two locations in 1978

Entry[a]	MOIST %	RATE 1-3	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
81	14.5	2.8	2.7	64.6	58.2	1.11	8.6	21.0
82	19.3	1.7	5.2	74.4	64.0	1.17	8.7	20.0
83	14.8	1.3	6.9	72.2	63.3	1.39	6.4	21.0
84	16.2	1.3	4.7	87.3	75.2	1.13	6.8	22.7
85	16.0	1.0	4.4	75.4	67.2	1.12	8.0	22.0
86	14.4	1.2	2.6	67.4	58.5	1.15	5.8	19.3
87	14.8	2.5	6.1	66.4	59.0	1.12	9.2	22.0
88	15.3	1.7	5.1	68.4	59.8	1.15	9.2	22.7
89	15.4	1.0	5.3	65.0	54.7	1.19	6.0	22.0
90	13.1	1.3	2.9	55.0	48.8	1.13	9.9	22.0
91	15.7	1.2	4.7	73.1	60.8	1.21	8.3	21.7
92	16.2	2.0	4.6	80.0	73.0	1.09	7.2	22.0
93	14.8	1.7	5.5	64.0	56.2	1.14	13.2	22.3
94	18.5	2.0	4.1	71.3	61.0	1.17	8.3	22.0
95	15.4	2.5	4.0	76.2	67.3	1.13	5.7	24.0
96	----	----	----	----	----	----	----	----
97	20.7	1.2	3.3	75.1	65.7	1.15	9.3	22.0
98	15.2	1.7	3.1	81.5	69.7	1.17	5.8	21.3
99	13.2	1.8	3.3	68.3	60.2	1.13	10.9	22.3
100	14.0	1.7	3.3	71.8	61.7	1.16	8.1	21.0
101	18.7	1.3	6.2	89.1	79.7	1.12	9.0	23.7
102	13.5	2.8	3.1	61.6	54.2	1.14	8.4	20.3
103	14.0	1.7	4.1	75.3	66.6	1.13	6.6	21.7
104	16.4	2.7	8.2	74.0	67.2	1.10	8.9	20.7
105	17.6	2.2	5.3	72.5	63.8	1.14	8.8	24.7
106	14.9	1.8	5.1	68.6	60.3	1.14	10.5	21.7
107	15.9	1.8	7.6	71.7	63.2	1.14	7.5	19.7
108	18.5	2.0	4.2	65.6	58.0	1.13	6.8	23.0
109	14.7	1.2	2.4	70.4	60.0	1.18	6.5	21.3
110	13.7	1.0	5.8	82.8	70.0	1.18	7.4	20.3
111	14.0	2.2	6.0	68.9	62.7	1.10	6.5	22.7
112	14.1	1.0	2.8	68.4	57.7	1.18	5.4	21.7
113	14.7	2.8	3.8	58.7	52.8	1.11	9.0	22.7
114	----	----	----	----	----	----	----	----
115	15.2	1.3	6.8	76.4	68.2	1.13	9.2	21.3
116	16.0	2.0	4.3	72.2	60.0	1.20	9.5	20.0
117	17.4	2.0	3.6	76.4	69.0	1.11	6.4	21.0
118	16.6	1.2	2.6	76.8	61.2	1.26	7.4	22.0
119	13.5	2.7	6.4	77.0	69.0	1.11	7.0	22.0
120	17.8	1.7	11.1	94.5	86.5	1.09	12.8	19.7
Mean	15.6	1.8	4.8	72.6	63.4	1.14	8.1	21.7
$LSD_{(.05)}$	2.5	0.6	3.4	9.3	9.8	0.07	3.3	2.0

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A30. Mean values of 39 hybrid entries for eight plant and grain traits at Ames in 1979

Entry[a]	MOIST %	RATE 1-3	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
81	17.8	3.0	13.6	81.1	69.0	1.18	6.9	29.0
82	20.8	2.0	13.0	82.5	71.0	1.16	7.5	29.0
83	18.1	2.0	17.1	84.6	71.7	1.18	9.7	28.3
84	18.7	2.0	14.4	103.5	87.0	1.19	5.1	31.7
85	20.1	1.3	14.9	91.5	78.7	1.16	8.5	29.7
86	16.8	1.3	13.1	82.7	69.0	1.20	6.0	29.3
87	15.1	3.0	16.1	76.4	66.7	1.14	6.9	27.0
88	18.6	1.0	15.5	83.9	70.3	1.19	6.5	30.0
89	17.8	1.3	15.3	78.3	65.0	1.21	8.7	28.3
90	23.3	2.0	13.2	60.7	53.3	1.14	10.5	29.3
91	15.2	2.0	13.4	81.2	67.7	1.20	6.7	31.0
92	19.7	2.7	16.5	87.1	77.0	1.13	5.9	29.0
93	17.9	2.0	19.5	73.0	65.3	1.12	11.7	29.3
94	17.2	2.3	13.0	82.7	68.3	1.21	11.2	29.0
95	16.1	2.0	17.6	90.5	76.7	1.18	7.2	32.0
96	19.7	2.0	15.2	74.2	63.3	1.17	11.4	27.0
97	21.0	2.0	13.2	85.9	72.3	1.19	8.6	31.0
98	----	----	----	----	----	----	----	----
99	15.0	1.7	12.3	82.0	69.3	1.18	9.7	29.7
100	15.2	1.7	12.3	84.1	69.0	1.22	7.9	28.3
101	18.9	1.0	14.7	98.2	84.0	1.17	8.2	29.3
102	16.3	3.0	16.3	74.1	61.3	1.22	7.8	28.3
103	17.2	2.3	16.4	79.7	68.3	1.17	7.7	30.3
104	16.7	3.0	22.9	84.5	75.3	1.12	9.6	28.7
105	16.8	2.7	18.2	91.1	72.0	1.27	8.7	29.3
106	19.0	1.7	17.2	83.5	71.3	1.17	11.5	28.0
107	17.6	2.3	12.9	78.3	67.3	1.16	6.4	29.3
108	21.9	3.0	21.5	83.5	74.0	1.13	8.7	30.3
109	17.0	1.0	13.7	84.4	71.7	1.18	6.7	30.3
110	19.1	1.0	13.6	100.9	83.0	1.22	8.5	29.0
111	16.7	3.0	16.2	85.4	72.3	1.18	8.3	30.3
112	16.8	1.3	13.9	88.1	73.3	1.20	8.0	29.0
113	18.7	3.0	13.0	74.7	64.0	1.17	8.2	28.7
114	19.8	2.0	15.3	87.6	74.3	1.18	5.1	27.3
115	17.2	2.0	14.8	90.4	79.0	1.15	8.2	29.7
116	18.3	3.0	16.9	82.0	69.7	1.18	8.5	27.7
117	17.5	2.0	13.7	82.3	69.7	1.18	6.9	30.7
118	18.4	1.0	11.3	86.5	70.7	1.22	6.8	29.0
119	16.8	2.7	14.0	76.0	65.7	1.16	7.0	29.7
120	19.3	2.0	26.5	97.0	85.0	1.14	10.4	31.4
Mean	18.0	2.1	15.4	84.0	71.4	1.18	8.2	29.3
$LSD_{(.05)}$	4.6	0.7	4.8	8.4	7.7	0.07	3.8	1.8

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A31. Mean values of 39 hybrid entries for seven grain traits at Ankeny in 1979

Entry[a]	MOIST %	RATE 1-3	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance
81	16.5	3.0	9.4	77.4	66.7	1.16	8.5
82	21.3	1.7	10.4	77.1	67.6	1.14	8.5
83	16.1	2.0	9.2	85.0	67.3	1.26	8.0
84	17.0	1.0	10.8	97.8	77.7	1.28	6.5
85	17.7	1.0	9.7	91.1	77.3	1.18	6.0
86	16.3	1.3	11.0	79.2	63.7	1.25	7.1
87	18.1	2.7	9.7	74.4	62.0	1.20	10.1
88	17.2	1.0	9.0	82.9	67.7	1.23	8.3
89	15.3	2.0	9.9	82.6	69.0	1.20	7.7
90	17.0	2.0	11.9	80.1	69.7	1.15	10.0
91	18.0	1.3	11.3	80.6	66.0	1.22	7.5
92	21.4	2.7	12.5	88.5	77.7	1.14	8.5
93	17.4	1.7	12.7	82.7	71.0	1.16	12.9
94	18.5	1.7	8.7	81.2	67.7	1.20	8.9
95	16.3	2.3	8.4	80.5	68.3	1.18	6.4
96	18.6	2.0	9.5	81.1	67.7	1.20	12.1
97	20.0	2.0	11.2	80.2	68.3	1.17	8.2
98	----	----	----	----	----	----	----
99	16.9	2.0	9.7	82.2	70.0	1.17	12.0
100	15.1	1.0	9.6	82.4	66.7	1.24	7.9
101	18.5	1.3	13.6	90.8	77.0	1.18	8.7
102	16.1	2.0	8.4	76.5	62.7	1.22	8.7
103	16.6	2.0	9.7	81.5	67.0	1.22	11.4
104	16.0	3.0	17.5	90.2	78.7	1.15	8.6
105	16.6	2.0	14.1	82.2	71.3	1.15	8.8
106	17.7	2.0	12.6	85.5	75.0	1.14	9.3
107	17.8	2.7	14.6	84.3	72.3	1.17	7.5
108	16.9	3.0	13.6	82.8	71.3	1.16	6.9
109	16.5	1.0	8.6	87.2	73.7	1.19	9.0
110	15.6	1.0	10.1	87.4	71.3	1.23	6.4
111	15.9	3.0	8.0	77.2	65.7	1.18	6.6
112	15.7	1.0	9.2	85.2	70.7	1.21	7.2
113	17.4	2.7	11.3	76.2	67.3	1.13	9.0
114	16.5	1.3	13.3	84.5	72.3	1.17	8.5
115	17.7	2.0	12.6	87.2	73.0	1.20	8.9
116	18.0	2.0	9.6	79.2	68.0	1.17	13.1
117	17.8	2.3	11.4	80.9	67.0	1.21	9.8
118	16.6	1.7	9.4	81.1	66.7	1.22	12.2
119	15.9	2.7	9.4	84.8	71.0	1.20	8.1
120	16.9	2.0	15.1	92.8	78.3	1.18	10.0
Mean	17.2	1.9	11.0	83.2	70.1	1.19	8.8
$LSD_{(.05)}$	2.1	0.6	3.2	6.8	7.5	0.09	3.4

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A32. Mean values of 39 hybrid entries for eight plant and grain traits data combined over two locations in 1979

Entry[a]	MOIST %	RATE 1-3	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
81	17.1	3.0	11.5	79.2	67.8	1.17	7.7	29.0
82	21.0	1.8	11.7	79.8	69.3	1.15	8.0	29.0
83	17.1	2.0	13.2	84.8	69.5	1.22	8.9	28.3
84	17.9	1.5	12.6	100.6	82.3	1.23	5.8	31.7
85	18.9	1.2	12.3	91.3	78.0	1.17	7.3	29.7
86	16.6	1.3	12.1	81.0	66.3	1.22	6.5	29.3
87	16.6	2.8	12.9	75.4	64.3	1.17	8.5	27.0
88	17.9	1.0	12.2	83.4	69.0	1.21	7.4	30.0
89	16.6	1.7	12.6	80.5	67.0	1.20	8.2	28.3
90	20.2	2.0	12.5	70.4	61.5	1.14	10.2	29.3
91	16.6	1.7	12.3	80.9	66.8	1.21	7.1	31.0
92	20.6	2.7	14.5	87.8	77.3	1.14	7.2	29.0
93	17.7	1.8	16.1	77.9	68.2	1.14	12.3	29.3
94	17.8	2.0	10.8	82.0	68.0	1.21	10.0	29.0
95	16.2	2.2	13.0	85.5	72.5	1.18	6.8	32.0
96	19.1	2.0	12.4	77.7	65.5	1.18	11.8	27.0
97	20.5	2.0	12.2	83.1	70.3	1.18	8.4	31.0
98	----	----	----	----	----	----	----	----
99	15.9	1.8	11.0	82.1	69.7	1.18	10.9	29.7
100	16.6	1.7	12.6	80.5	67.0	1.20	8.2	28.3
101	18.7	1.2	14.1	94.5	80.5	1.17	8.5	29.3
102	16.2	2.5	12.3	75.3	62.0	1.22	8.3	29.7
103	16.9	2.2	13.1	80.6	67.6	1.19	9.6	30.3
104	16.3	3.0	20.2	87.4	77.0	1.13	9.1	28.7
105	16.7	2.3	16.2	86.6	71.7	1.21	8.7	29.3
106	18.3	1.8	14.9	84.5	73.2	1.15	10.4	28.0
107	17.7	2.5	13.7	81.3	69.8	1.16	6.9	29.3
108	19.4	3.0	17.6	83.2	72.7	1.14	7.8	30.3
109	16.8	1.0	11.1	85.8	72.7	1.18	7.8	30.3
110	17.4	1.0	11.9	94.2	77.2	1.22	7.4	29.0
111	16.3	3.0	12.1	81.3	69.0	1.18	7.5	30.3
112	16.2	1.2	11.6	86.6	72.0	1.20	7.6	29.0
113	18.0	2.8	12.2	75.4	65.7	1.15	8.6	28.7
114	17.8	1.7	14.3	86.0	73.3	1.17	6.8	27.3
115	17.4	2.0	13.7	88.8	76.0	1.17	8.5	29.7
116	18.1	2.5	14.0	80.9	69.0	1.18	10.8	27.7
117	17.7	2.2	12.6	81.6	68.3	1.20	8.4	30.7
118	17.5	1.3	10.4	83.8	68.7	1.22	9.5	29.0
119	16.4	2.7	11.7	80.4	68.3	1.18	7.5	29.7
120	18.1	2.0	20.8	94.9	81.7	1.16	10.2	31.0
Mean	17.6	2.0	13.2	83.6	70.7	1.18	8.5	29.3
$LSD_{(.05)}$	2.5	0.5	2.8	8.6	7.3	0.05	2.6	1.8

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A33. Mean values of 40 hybrid entries for eight plant and grain traits data combined over locations and years

Entry[a]	MOIST %	RATE 1-5	BREAK %	WT g	VOL ml	DEN g/ml	GRN[b] Absorbance	DATE Days
81	16.9	3.3	7.9	69.6	59.8	1.16	8.2	25.0
82	21.2	2.4	9.6	76.1	64.1	1.19	8.4	24.5
83	17.2	2.3	11.1	78.2	65.0	1.20	7.6	24.6
84	18.1	2.1	9.8	93.8	77.6	1.21	6.3	27.2
85	19.2	1.8	9.0	83.8	71.6	1.18	7.6	25.8
86	16.2	1.8	7.2	69.9	57.4	1.23	6.2	24.3
87	16.8	3.2	11.7	69.1	58.1	1.20	8.8	24.5
88	17.3	1.9	8.8	72.6	59.8	1.22	8.3	26.4
89	17.1	1.9	9.2	70.9	58.1	1.22	7.1	25.2
90	16.6	2.4	8.9	64.9	56.0	1.16	10.0	25.6
91	17.2	2.3	10.0	75.3	61.9	1.22	7.7	26.4
92	19.2	2.9	10.8	85.4	74.9	1.14	7.2	25.5
93	17.1	2.2	13.0	66.8	58.1	1.15	12.7	25.8
94	19.0	2.7	7.8	75.9	63.1	1.21	9.2	25.5
95	16.8	3.0	9.8	80.6	68.6	1.17	6.2	28.0
96	18.8	2.8	10.0	72.1	59.7	1.21	11.8	27.0
97	21.3	2.3	9.0	78.0	64.7	1.21	8.9	26.5
98	17.8	2.8	6.9	83.2	68.1	1.22	5.8	21.3
99	15.5	2.5	8.2	76.4	63.5	1.21	10.9	26.0
100	15.2	2.2	8.8	74.5	61.5	1.21	8.0	24.6
101	20.4	2.1	11.4	94.1	80.1	1.17	8.7	26.5
102	15.4	3.2	10.0	67.0	56.6	1.18	8.3	24.3
103	16.5	2.6	9.4	78.0	65.4	1.19	8.1	26.0
104	16.9	3.3	15.5	81.4	71.2	1.14	9.0	24.7
105	17.4	2.9	11.7	76.6	64.6	1.19	8.8	27.0
106	17.6	2.4	12.1	79.6	67.6	1.18	10.4	24.8
107	17.8	2.7	11.6	77.1	65.8	1.17	7.2	24.5
108	20.0	3.1	13.1	71.9	62.7	1.15	7.3	26.6
109	18.0	1.7	7.2	77.7	64.0	1.22	7.2	25.8
110	16.0	1.7	10.2	88.1	71.8	1.23	7.4	24.6
111	15.0	3.2	8.2	70.5	60.3	1.18	7.0	26.5
112	15.3	1.4	8.1	75.0	61.4	1.22	6.5	25.4
113	16.6	3.5	8.3	63.2	54.8	1.16	8.8	25.7
114	18.0	2.6	12.4	81.7	67.5	1.21	6.8	27.3
115	17.4	2.4	10.8	81.3	69.2	1.18	8.9	25.5
116	18.7	2.9	10.4	76.3	63.2	1.21	10.2	23.8
117	18.5	2.6	9.2	77.9	66.3	1.18	7.4	25.8
118	17.6	1.9	6.5	78.2	62.2	1.26	8.6	25.5
119	16.0	3.3	11.6	80.2	68.7	1.17	7.3	25.8
120	19.3	2.3	17.1	99.8	86.6	1.15	11.5	25.4
Mean	17.6	2.5	10.1	77.3	65.0	1.19	8.3	25.5
$LSD_{(.05)}$	1.7	0.4	2.2	5.9	5.2	0.04	2.0	1.6

[a]Inbred 1 x Inbred 2 = Hybrid 81, etc.

[b]Values were multiplied by 10^2.

Table A34. Analyses of variance for six grain traits for 40 hybrid entries at Ames in 1976

Source	d.f.	Mean squares					
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]
Replications	2	10.63	12.71	5.28	206.89	131.51	23.48
Genotypes	39	23.37**	103.07**	30.40**	384.31**	260.36**	41.93**
Error	78	9.14	8.01	2.95	29.39	20.27	16.25

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

**Significant at the 0.01 level of probability.

Table A35. Analyses of variance for six grain traits for 40 hybrid entries at Ankeny in 1976

		Mean squares					
Source	d.f.	MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]
Replications	2	5.62	5.83	4.83	19.30	37.41	29.64
Genotypes	39	13.87**	88.97**	41.84**	393.71**	282.93**	78.03*
Error	78	4.57	12.24	13.76	28.85	22.99	47.52

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A36. Analyses of variance for six grain traits for 40 hybrid entries data combined over two locations in 1976

Source	d.f.	Mean squares					
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]
Locations (L)	1	2125.34	338.44	1603.22	2805.08	1787.60	5.79
Replications/L	4	8.12	9.27	5.05	113.09	84.46	26.56
Genotypes (G)	39	28.60**	178.61**	62.74**	729.66**	509.47**	95.32**
G x L	39	8.64	13.43	9.50	48.36*	33.82*	24.64
Error	156	6.86	10.12	8.35	29.12	21.63	31.88

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A37. Analyses of variance for eight plant and grain traits for 38 hybrid entries at Ames in 1978

Source	d.f.	Mean squares							
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[a]	GRN[b]	DATE
Replications	2	1.14	36.37	8.08	12.52	27.51	196.41	8.22	56.11
Genotypes	37	12.63**	97.80**	13.71**	275.10**	254.01**	58.56	16.65**	4.20**
Error[c]	74	0.82	31.65	3.02	45.40	30.87	41.02	3.26	1.56

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A43 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A38. Analyses of variance for seven grain traits for 38 hybrid entries at Atomic Energy in 1978

Source	d.f.	Mean squares						
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]
Replications	2	0.92	13.19	2.10	19.39	19.20	4.66	7.26
Genotypes	37	11.79**	129.27**	14.47*	167.27**	136.62**	54.63	11.31**
Error[c]	74	1.32	16.99	7.13	20.86	21.62	29.14	4.64

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4

[c]See Table A43 for error degrees of freedom.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A39. Analyses of variance for eight plant and grain traits for 38 hybrid entries data combined over two locations in 1978

Source	d.f.	Mean squares MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Locations (L)	1(0)[c]	381.69	11.06	0.41	10633.57	6203.77	38.34	325.45	-------
Replications/L	4(2)	1.03	24.78	5.09	15.96	23.35	10.05	7.74	56.11
Genotypes (G)	37(37)	19.89**	196.46**	19.82**	378.76**	320.69**	7.56*	19.97**	4.20**
G x L	37(0)	4.53**	30.60	8.36*	63.61**	69.94**	3.76	8.19**	-------
Error[d]	148(74)	1.07	24.32	5.04	33.21	26.21	3.50	3.95	1.56

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]Degrees of freedom for DATE.

[d]See Table A43 for error degrees of freedom.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A40. Analyses of variance for eight plant and grain traits for 39 hybrid entries at Ames in 1979

Source	d.f.	Mean squares							
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Replications	2	8.15	5.98	25.57	51.18	36.32	2.55	39.98	1.13
Genotypes	38	10.33	131.35**	28.07**	194.35**	133.21**	28.91*	8.71*	4.16**
Error[c]	76	7.84	19.14	8.44	25.96	21.74	17.03	5.37	1.12

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A43 for error degrees of freedom.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A41. Analyses of variance for seven grain traits for 39 hybrid entries at Ankeny in 1979

		Mean squares						
Source	d.f.	MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]
Replications	2	0.69	17.95	4.45	21.31	0.34	62.88	10.99
Genotypes	38	5.95**	121.86**	14.06**	73.59**	56.85**	36.49	9.98**
Error[c]	76	1.62	12.69	3.66	16.88	20.50	27.32	4.29

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]See Table A43 for error degrees of freedom.

**Significant at the 0.01 level of probability.

Table A42. Analyses of variance for eight plant and grain traits for 39 hybrid entries data combined over two locations in 1979

Source	d.f.	Mean squares							
		MOIST	RATE[a]	BREAK	WT	VOL	DEN[b]	GRN[b]	DATE
Locations (L)	1(0)[c]	39.41	109.40	1174.82	30.36	94.37	89.86	25.26	------
Replications/L	4(2)	4.42	11.97	15.01	36.25	18.33	32.71	25.49	1.33
Genotypes (G)	38(38)	11.26**	226.27**	31.62**	213.44**	150.67**	46.81**	12.99**	4.16**
G x L	38(0)	5.01	29.94*	10.52*	54.51**	39.39**	18.60	5.69	------
Error[d]	152(76)	4.71	15.91	6.06	21.45	21.12	22.14	4.82	1.12

[a]Mean squares were multiplied by 10^2.

[b]Mean squares were multiplied by 10^4.

[c]Degrees of freedom for DATE.

[d]See Table A43 for error degrees of freedom.

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A43. Error degrees of freedom for hybrid analysis of variance

Analysis	Trait							
	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
1976 Ames	78	78	78	78	78	78	---	---
1976 Ankeny	78	78	78	78	78	78	---	---
1976 Combined	156	156	156	156	156	156	---	---
1978 Ames	74	73	73	74	72	72	74	74
1978 Atomic Energy	74	73	71	73	73	73	74	---
1978 Combined	148	146	144	147	145	145	148	74
1979 Ames	75	76	76	76	76	76	75	76
1979 Ankeny	76	76	75	75	75	75	76	---
1979 Combined	151	152	151	151	151	151	151	76
Combined	455	454	451	454	452	452	299	150

Table A44. Correlation coefficients between six grain traits for 40 hybrid entries, at Ames 1976 (simple _r_ values above and genotypic _r_ values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST		-0.14	0.05	0.45**	0.41**	0.21
RATE	-0.17		0.38*	-0.03	0.05	-0.46**
BREAK	0.00	0.43		0.31	0.39*	-0.46**
WT	0.52	-0.04	0.31		0.98**	-0.01
VOL	0.46	0.04	0.40	0.99		-0.16
DEN	0.40	-0.62	-0.62	-0.01	-0.15	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A45. Correlation coefficients between six grain traits for 40 hybrid entries, at Ankeny 1976 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST		0.16	0.36*	0.49	0.51*	-0.14
RATE	0.20		0.26	-0.02	0.11	-0.50**
BREAK	0.49	0.40		0.45**	0.56**	-0.48**
WT	0.52	-0.01	0.52		0.97**	-0.02
VOL	0.56	0.12	0.67	0.98		-0.26
DEN	-0.35	-0.82	-0.96	-0.10	-0.24	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A46. Correlation coefficients between six grain traits for 40 hybrid entries, data combined over locations in 1976 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST		-0.04	0.20	0.48**	0.47**	0.02
RATE	-0.06		0.34*	-0.04	0.06	-0.54*
BREAK	0.23	0.38		0.39*	0.49**	-0.59**
WT	0.52	-0.06	0.39		0.98**	-0.02
VOL	0.51	0.05	0.51	0.98		-0.22
DEN	0.01	-0.63	-0.76	-0.05	-0.22	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A47. Correlation coefficients between eight plant and grain traits for 38 hybrid entries, at Ames 1978 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.16	0.27	0.45**	0.47**	-0.15	0.44**	-0.02
RATE	-0.18		0.21	-0.24	-0.12	-0.28	-0.13	0.08
BREAK	0.28	0.40		0.43**	0.48**	-0.34*	0.33*	-0.16
WT	0.49	-0.30	0.54		0.96**	-0.18	0.07	-0.11
VOL	0.51	-0.14	0.58	0.98		-0.44**	0.13	-0.10
DEN	-0.32	0.77	-0.72	-0.59	-0.70		-0.17	-0.07
GRN	0.48	-0.15	0.36	0.05	-0.15	-0.53		-0.04
DATE	-0.06	0.22	-0.23	-0.10	-0.11	0.03	-0.09	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A48. Correlation coefficients between seven grain traits for 38 hybrid entries, at Atomic Energy 1978 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN
MOIST		-0.16	0.03	0.42*	0.36*	0.18	-0.18
RATE	-0.17		-0.20	-0.36*	-0.22	-0.46**	0.31
BREAK	0.01	-0.25		0.37*	0.43**	-0.17	0.10
WT	0.46	-0.44	0.48		0.95**	0.13	-0.23
VOL	0.38	-0.27	0.57	0.97		-0.18	-0.15
DEN	0.34	-0.75	-0.36	0.18	-0.07		-0.25
GRN	-0.34	0.45	0.08	-0.25	-0.15	-0.41	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A49. Correlation coefficients between eight plant and grain traits for 38 hybrid entries, data combined over locations in 1978 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.15	0.19	0.42**	0.39*	0.03	0.12	-0.02
RATE	-0.13		0.01	-0.33*	-0.19	-0.47**	0.08	0.08
BREAK	0.28	0.04		0.45**	0.54**	-0.40*	0.36*	-0.16
WT	0.39	-0.39	0.55		0.96**	-0.06	-0.05	-0.11
VOL	0.35	-0.22	0.73	0.94		-0.31	0.04	-0.10
DEN	0.07	-0.22	-0.79	-0.07	-0.29		-0.22	-0.07
GRN	0.04	0.07	0.70	-0.05	0.05	-0.24		-0.04
DATE	-0.06	0.22	-0.23	-0.10	-0.11	0.03	-0.09	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A50. Correlation coefficients between eight plant and grain traits for 39 hybrid entries at Ames 1979 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		-0.08	0.11	-0.03	0.06	-0.36*	0.20	0.02
RATE	-0.20		0.34*	-0.34*	-0.26	-0.29	0.04	-0.14
BREAK	0.28	0.46		0.17	0.31	-0.43**	0.35*	0.09
WT	-0.01	-0.42	0.20		0.96**	0.25	-0.26	0.36*
VOL	0.28	-0.32	0.32	0.98		-0.02	-0.22	0.38*
DEN	-1.20	-0.56	-0.50	0.35	0.16		-0.19	-0.02
GRN	0.56	0.11	0.75	-0.43	-0.41	-0.21		-0.22
DATE	0.06	-0.14	0.01	0.48	0.50	-0.02	-0.41	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A51. Correlation coefficients between seven grain traits for 39 hybrid entries, at Ankeny 1979 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN
MOIST		0.09	0.16	-0.04	0.14	-0.38*	0.19
RATE	0.12		0.24	-0.35*	-0.10	-0.51**	0.10
BREAK	0.20	0.28		0.42**	0.61**	-0.44**	0.06
WT	-0.08	-0.42	0.49		0.89**	0.17	-0.22
VOL	0.12	-0.17	0.77	0.95		-0.29	-0.14
DEN	-0.71	-0.94	-0.90	0.40	0.11		-0.17
GRN	0.16	0.18	0.07	-0.24	-0.12	-0.48	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A52. Correlation coefficients between eight plant and grain traits for 39 hybrid entries, data combined over locations in 1979 (simple r values above and genotypic r values below the diagonal)

	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST		0.02	0.13	0.02	0.17	-0.49**	0.13	0.02
RATE	0.09		0.34*	-0.41**	-0.24	-0.50**	0.11	-0.14
BREAK	0.14	0.43		0.29	0.46**	-0.49**	0.22	0.09
WT	0.13	-0.52	0.37		0.95**	0.21	-0.34*	0.36*
VOL	0.36	-0.32	0.57	0.96		-0.12	-0.25	0.38*
DEN	-0.82	-0.69	-0.65	0.21	-0.08		-0.30	-0.02
GRN	0.02	0.18	0.20	-0.50	-0.38	-0.56		-0.22
DATE	0.06	-0.14	0.01	0.48	0.50	-0.02	-0.41	

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A53. Simple correlation coefficients between the mean of two inbred parents and their hybrid for six grain traits at Ames in 1976 for 40 hybrids and their parent lines

	Inbred					
Hybrid	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST	0.20	-0.18	0.04	0.38*	0.34*	0.21
RATE	0.20	0.56**	0.31*	0.14	0.21	-0.36*
BREAK	0.13	0.46**	0.65**	0.37**	0.46**	-0.33*
WT	0.31*	0.13	0.34*	0.61**	0.65**	-0.07
VOL	0.32*	0.18	0.40**	0.63**	0.68**	-0.14
DEN	-0.10	-0.31*	-0.33*	-0.14	-0.21	0.38*

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A54. Simple correlation coefficients between the mean of two inbred parents and their hybrid for six grain traits at Ankeny 1976 for 40 hybrids and their parent lines

	Inbred					
Hybrid	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST	0.48**	-0.05	0.30	0.38*	0.32*	0.10
RATE	0.27	0.56**	0.28	0.11	0.13	-0.16
BREAK	0.24	0.21	0.61**	0.46**	0.54**	-0.52**
WT	0.43**	0.05	0.42**	0.72**	0.72**	-0.28
VOL	0.40**	0.14	0.50**	0.73**	0.75**	-0.36*
DEN	0.04	-0.37*	-0.38*	-0.14	-0.21	0.37*

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A55. Simple correlation coefficients between the mean of two inbred parents and their hybrid for six grain traits data combined over two locations in 1976 for 40 hybrids and their parent lines

	Inbred					
Hybrid	MOIST	RATE	BREAK	WT	VOL	DEN
MOIST	0.42**	-0.15	0.23	0.44**	0.40**	0.14
RATE	0.27	0.56**	0.28	0.11	0.13	-0.16
BREAK	0.18	0.36*	0.58**	0.44**	0.53**	-0.55**
WT	0.43**	0.05	0.42**	0.72**	0.72**	-0.28
VOL	0.40**	0.14	0.50**	0.73**	0.75**	-0.36*
DEN	0.04	-0.37*	-0.38*	-0.14	-0.21	0.37*

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A56. Simple correlation coefficients between the mean of two inbred parents and their hybrid for eight plant and grain traits at Ames in 1978 for 38 hybrids and their parent lines

	Inbred							
Hybrid	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST	0.73**	-0.12	0.28	0.55**	0.53**	0.04	0.19	-0.31
RATE	-0.04	0.25	0.14	-0.05	-0.02	-0.07	-0.23	-0.13
BREAK	0.18	0.22	0.65**	0.50**	0.54**	-0.21	0.16	-0.09
WT	0.34*	0.02	0.61**	0.79**	0.75**	0.11	-0.04	-0.04
VOL	0.37*	0.05	0.64**	0.75**	0.75**	0.01	-0.01	-0.04
DEN	-0.15	-0.12	-0.35*	-0.07	-0.16	0.36*	-0.09	-0.05
GRN	0.29	-0.03	0.30	0.11	0.12	-0.05	-0.54**	-0.15
DATE	-0.15	0.16	-0.12	-0.04	-0.02	-0.02	-0.12	0.11

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A57. Simple correlation coefficients between the mean of two inbred parents and their hybrid for three grain traits at Atomic Energy in 1978 for 38 hybrids and their parent lines

	Inbred		
Hybrid	MOIST	RATE	BREAK
MOIST	0.44*	-0.33*	0.09
RATE	-0.20	0.39**	0.08
BREAK	0.03	0.33*	0.03

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A58. Simple correlation coefficients between the mean of two inbred parents and their hybrid for eight plant and grain traits data combined over two locations in 1978 for 38 hybrids and their parent lines

	Inbred							
Hybrid	MOIST	RATE	BREAK	WT	VOL	DEN	GRN	DATE
MOIST	0.69**	-0.25	0.12	0.55**	0.53**	0.04	0.19	-0.31
RATE	-0.19	0.42**	0.17	-0.05	-0.02	-0.07	-0.23	-0.13
BREAK	0.19	0.30	0.50**	-0.50**	0.54**	-0.21	0.16	-0.09
WT	0.34*	0.02	0.61**	0.79**	0.75**	0.11	-0.04	-0.04
VOL	0.37*	0.05	0.64**	0.75**	0.73**	0.01	-0.01	-0.04
DEN	-0.15	-0.12	-0.35*	-0.07	-0.16	0.36*	-0.09	-0.05
GRN	0.29	-0.03	0.30	0.11	0.12	-0.05	-0.54**	-0.15
DATE	-0.15	0.16	-0.12	-0.04	-0.02	-0.02	-0.12	0.11

*Significant at the 0.05 level of probability.

**Significant at the 0.01 level of probability.

Table A59. Weights for each trait included in the restricted selection indices

Trait	Weights R1	Weights R2
BREAK	- .760296	- .779098
MOIST	.004288	.032726
RATE	-1.3119	-1.32264
WT	.149551	.141071
GRN	-8.15346	-7.88362